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AN INVESTIGATION INTO THE LATERAL STABILITY OF THE M1037 TRUCK PULLING THE M101 TRAILER

SEPTEMBER 1988

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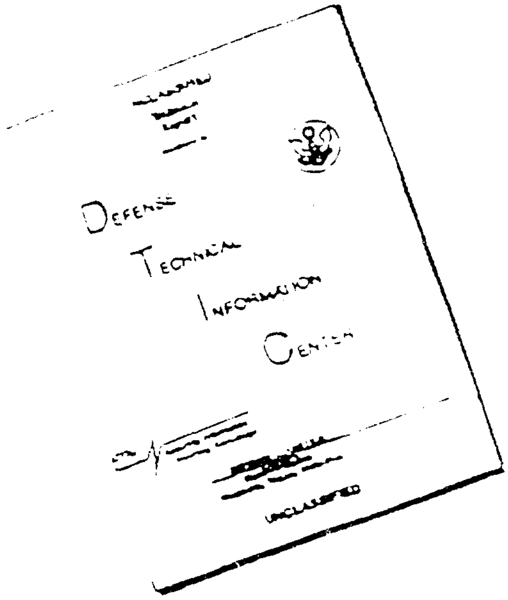

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This report documents an investigation into the lateral stability of the M1037 Truck pulling the M101 Trailer. The Multibody Dynamic Simulation Program Dynamic Analysis and Design System (DADS) was used to produce a Dynamic Simulation Model for both the M1037 Truck with the Mobile Subscriber Equipment (MSE) payload and the M101 Trailer systems. The simulation model was validated with instrumented road tests. Once the validity of the model was established, it was used to determine the stability boundaries of the M1037/M101 System for lane change, steady turn and nump course maneuvers. The report presents recommendations to improve the dynamic stability of the system.

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TABLE OF CONTENTS

1.0. INTRODUCTION 9

2.0. OBJECTIVES 10

3.0. CONCLUSIONS 10

4.0. RECOMMENDATIONS 11

5.0. DISCUSSION 12
- 5.1. Roll/Yaw Instability 12
- 5.2. Analysis/Simulation Approach 13
- 5.3. The Simulation Model 13
  - 5.3.1. The Truck Simulation Model 13
  - 5.3.2. Trailer Simulation Model 28
  - 5.3.3. The Tire Model 36
  - 5.3.4. The Driver Model 45
  - 5.3.5. Implementation of the Driver Model 54
- 5.4. Validation of Simulation Model 56
  - 5.4.1 Validation of the M1037/M101 Simulation Model 61
- 5.5. M1037 Simulation Results 75
  - 5.5.1. Lane Change 75
  - 5.5.2. Steady Turn 80
  - 5.5.3. Bump Course 85
  - 5.5.4. Maneuvering on an Inclined Slope 91
- 5.6. M1037/M101 Simulation Results 93
  - 5.6.1. Lane Change 93
  - 5.6.2. Steady Turn 99
  - 5.6.3. Bump Course 105
  - 5.5.4. Maneuvering on an Inclined Slope 112
- 5.7. Analytical results 114
  - 5.7.1. Yaw Plane Modeling 114
  - 5.7.1. Inaccuracies 114
  - 5.7.2. Linearized Equations 115
  - 5.7.3. Vehicle Stability During Forward Travel 117
- 5.8. Vehicle braking 120

5.8.1. M1037 Braking Results 120
5.8.2. M1037/M101 Braking Results 122

LIST OF REFERENCES 124

APPENDIX A: Test Plan for Road Testing A-1
APPENDIX B: Vehicle Data Files B-1
APPENDIX C: Tire Model FORTRAN Source Code C-1
APPENDIX D: Driver Model Fortran Source Code D-1

DISTRIBUTION LIST Dist-1

LIST OF ILLUSTRATIONS

Figure 5.3.1-1 The M1037 truck 17
Figure 5.3.1-2 Schematic representation for the M1037 truck 18
Figure 5.3.1-3 The M1037 front left suspension, front view 19
Figure 5.3.1-4 The M1037 front left suspension, left side view. 20
Figure 5.3.1-5 The M1037 front left suspension, top view 21
Figure 5.3.1-6 The M1037 rear left suspension, rear view. 22
Figure 5.3.1-7 The M1037 front left suspension, left side view 23
Figure 5.3.1-8 The M1037 rear left suspension, top view 24
Figure 5.3.1-9 The M1037 steering left side, top view 25
Figure 5.3.1-10 The M1037 steering right side, top view 26
Figure 5.3.1-11 The M1037 steering, left side view 27
Figure 5.3.2-1 The M101 trailer 29
Figure 5.3.2-2 Schematic representation of the M101 trailer. 30
Figure 5.3.2-3 Force deflection characteristics of the M101 trailer leaf spring. 34
Figure 5.3.2-4 Damping characteristics of M101 shocks 35
Figure 5.3.3-1 The flow of control for tire model 37
Figure 5.3.3-2 The forces and moments acting upon a tire 38
Figure 5.3.3-3 The trailer tire lateral force versus slip data for the 36x12.50-16.5LT tire at 20 psi 40
Figure 5.3.3-4 The trailer tire lateral force versus slip data for the 36x12.50-16.5LT tire at 28 psi 41
Figure 5.3.3-5 The trailer tire lateral force versus slip data 42
Figure 5.3.3-6 The trailer tire aligning moment versus slip data 43
Figure 5.3.3-7 The trailer tire longitudinal/vertical force versus longitudinal slip data. 44
Figure 5.3.4-1 Driver control strategy 46
Figure 5.3.4-2 Closed loop frequency response gain (from Ref. 9) 48
Figure 5.3.4-3 Preview control strategy 50
Figure 5.3.4-2 Single point preview control block diagram. 52
Figure 5.3.5-1 Driver model implementation 55
Figure 5.4-1 100 by 12 ft lane change course. 59
Figure 5.4-2 Bump course. 60
Figure 5.4.1-1 Lateral vehicle acceleration for a 45 mph 100 ft by 12 ft lane change 62
Figure 5.4.1-2 Lateral trailer acceleration for a 45 mph 100 ft by 12 ft lane change. 62
Figure 5.4.1-3 Vehicle yaw rate for a 45 mph 100 ft by 12 ft lane change 63

Figure 5.4.1-4 Vehicle roll for a 45 mph 100 ft by 12 ft lane change ... 63
Figure 5.4.1-5 Articulation angle for a 45 mph 100 ft by 12 ft lane change. ... 64
Figure 5.4.1-6 Trailer right axle displacement for a 45 mph 100 ft by 12 ft lane change ... 64
Figure 5.4.1-7 Trailer left axle displacement for a 45 mph 100 ft by 12 ft lane change. ... 65
Figure 5.4.1-8 Steering wheel angle for a 45 mph 100 ft by 12 ft lane change ... 65
Figure 5.4.1-9 Lateral vehicle acceleration for a 45 mph 500 ft radius turn ... 67
Figure 5.4.1-10 Lateral trailer acceleration for a 45 mph 500 ft radius turn ... 67
Figure 5.4.1-11 Vehicle yaw rate for a 45 mph 500 ft radius turn. ... 68
Figure 5.4.1-12 Articulation angle for a 45 mph 500 ft radius turn ... 68
Figure 5.4.1-13 Trailer right axle displacement for a 500 ft radius turn ... 69
Figure 5.4.1-14 Trailer left axle displacement for a 45 mph 500 ft radius turn ... 69
Figure 5.4.1-15 Steering wheel angle for a 45 mph 500 ft radius turn. ... 70
Figure 5.4.1-16 Lateral vehicle acceleration for a 6 inch bump course at 10 mph ... 72
Figure 5.4.1-17 Lateral trailer acceleration for a 6 inch bump course at 10 mph. ... 72
Figure 5.4.1-18 Vehicle roll for a 6 inch bump course at 10 mph ... 73
Figure 5.4.1-19 Articulation angle for a 6 inch bump course at 10 mph. ... 73
Figure 5.4.1-20 Trailer right axle displacement for a 6 inch bump course at 10 mph ... 74
Figure 5.4.1-21 Trailer left axle displacement for a 6 inch bump course at 10 mph. ... 74
Figure 5.5.1-1 M1037 CG position for a 100 ft by 12 ft 60 mph lane change. ... 77
Figure 5.5.1-2 M1037 CG Lateral acceleration of vehicle CG for a 100 ft by 12 ft 60 mph lane change. ... 77
Figure 5.5.1-3 M1037 yaw rate for a 100 ft by 12 ft 60 mph lane change ... 78
Figure 5.5.1-4 M1037 vertical tire deflections for a 100 ft by 12 ft 60 mph lane change. ... 78
Figure 5.5.1-5 M1037 tire slip angles for a 100 ft by 12 ft 60 mph lane change ... 79
Figure 5.5.1-6 M1037 steer angle for a 100 ft by 12 ft 60 mph lane change. ... 79
Figure 5.5.2-1 M1037 CG position, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph. ... 82
Figure 5.5.2-2 M1037 CG lateral acceleration, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph. ... 82
Figure 5.5.2-3 M1037 yaw rate, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph. ... 83
Figure 5.5.2-5 M1037 tire slip angles, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph. ... 84
Figure 5.5.2-6 M1037 steer angle, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph. ... 84
Figure 5.5.3-1 M1037 chassis CG vertical position, 6 inch bump course, 15 mph ... 87
Figure 5.5.3-2 M1037 tire vertical position, 6 inch bump course, 15 mph. ... 87

Figure 5.5.3-3 M1037 chassis roll angle, 6 inch bump course, 15 mph. 88
Figure 5.5.3-4 M1037 chassis vertical acceleration, 6 inch bump course, 15 mph.............. 88
Figure 5.5.3-5 M1037 chassis CG lateral acceleration, 6 inch bump course, 15 mph............ 89
Figure 5.5.3-6 M1037 chassis yaw rate, 6 inch bump course, 15 mph.......................... 89
Figure 5.5.3-8 M1037 wheel deflection, 6 inch bump course, 15 mph. 90
Figure 5.6.1-1 M1037/M101 CG position for a 100 ft by 12 ft 60 mph lane change.............. 95
Figure 5.6.1-2 M1037/M101 CG Lateral acceleration of vehicle CG for a 100 ft by 12 ft 60 mph lane change... 95
Figure 5.6.1-3 M1037/M101 yaw rate for a 100 ft by 12 ft 60 mph lane change................. 96
Figure 5.6.1-4 M1037/M101 vertical tire deflections for a 100 ft by 12 ft 60 mph lane change.. 96
Figure 5.6.1-5 M1037/M101 tire slip angles for a 100 ft by 12 ft 60 mph lane change. 97
Figure 5.6.1-6 M1037/M101 steer angle for a 100 ft by 12 ft 60 mph lane change............... 97
Figure 5.6.1-7 M1037/M101 articulation angle for a 100 ft by 12 ft 60 mph lane change. 98
Figure 5.6.1-8 M1037/M101 roll angle for a 100 ft by 12 ft 60 mph lane change. 98
Figure 5.6.2-1 M1037/M101 CG position for a 500 ft radius steady turn simulation, 45 mph. . 101
Figure 5.6.2-2 M1037/M101 CG Lateral acceleration of vehicle CG for a 500 ft radius steady turn simulation, 45 mph 101
Figure 5.6.2-3 M1037/M101 yaw rate for a 500 ft radius steady turn simulation, 45 mph....... 102
Figure 5.6.2-4 M1037/M101 vertical tire deflections for a 500 ft radius steady turn simulation, 45 mph. 102
Figure 5.6.2-5 M1037/M101 tire slip angles for a 500 ft radius steady turn simulation, 45 mph. 103
Figure 5.5.1-6 M1037/M101 steer angle for a 500 ft radius steady turn simulation, 45 mph. ... 103
Figure 5.6.2-7 M1037/M101 articulation angle for a 500 ft radius steady turn simulation, 45 mph. 104
Figure 5.6.2-8 M1037/M101 roll angle for a 500 ft radius steady turn simulation, 45 mph...... 104
Figure 5.6.3-1 M1037/M101 CG position for the 6 inch bump course simulation, 15 mph..... 107
Figure 5.6.3-2 M1037/M101 CG Lateral acceleration of vehicle CG for the 6 inch bump course simulation, 15 mph... 107
Figure 5.6.3-3 M1037/M101 yaw rate for the 6 inch bump course simulation, 15 mph. 108
Figure 5.6.3-4 M1037/M101 vertical tire deflections for the 6 inch bump course simulation, 15 mph.. 108
Figure 5.6.3-5 M1037/M101 articulation angle for the 6 inch bump course simulation, 15 mph. 109
Figure 5.5.3-6 M1037/M101 chassis roll angle for the 6 inch bump course simulation, 15 mph. 109

Figure 5.6.3-7 M1037/M101 chassis CG vertical acceleration for the 6 inch bump course simulation, 15 mph. 110
Figure 5.6.3-8 M1037/M101 vertical wheel position for the 6 inch bump course simulation, 15 mph 110
Figure 5.6.3-9 M1037/M101 chassis roll angle for the 6 inch bump course simulation, 15 mph. 111
Figure 5.7.2-1 Yaw plane jackknife mode. 116
Figure 5.7.2-2 Yaw Plane articulation oscillatory mode 116
Figure 5.7.3-1 M1037/M101 eigenvalues during straight line motion 118
Figure 5.7.3-2 M1037/M101 articulation mode damping ratio during straight line motion. 119

LIST OF TABLES

Table 5.3.1-1 Vehicle parameters used for the vehicle and trailer simulation....................... 15
Table 5.3.1-2 Element types used in M1037 simulation model.................................... 16
Table 5.3.2-1 Vehicle parameters used for the M101 simulation model............................. 31
Table 5.3.2-2 Element types used in the trailer simulation model.................................. 32
Table 5.4-1 Truck/Trailer measurements... 57
Table 5.5.1-1 Peak values for the M1037 100 ft by 12 ft lane change simulations................ 76
Table 5.5.2-1 Peak values for the M1037 500 ft radius steady turn simulations.................. 81
Table 5.5.3-1 Peak values for the M1037 bump course simulations............................... 86
Table 5.5.4-1 Peak values for the M1037 inclined slope simulations.............................. 92
Table 5.6.1-1 Peak values for the M1037/M101 100 ft by 12 ft lane change simulations......... 94
Table 5.6.2-1 Peak values for the M1037/M101 500 ft radius steady turn simulations........... 100
Table 5.6.3-1 Peak values for the M1037/M101 bump course simulations......................... 106
Table 5.6.4-1 Peak values for the M1037/M101 inclined slope lane change simulations 113
Table 5.8.1-1 Results from M1037 braking tests.. 121
Table 5.8.2-1 Results from the M1037/M101 braking tests.. 123

1.0. INTRODUCTION

This report presents the final results of an analytical and experimental program to evaluate the stability proprieties of the M1037 and the M101 trailer system for on road operation.

The Analytical and Physical Simulation Branch (AMSTA-RYA) was requested by the Light Tactical Vehicle Project Manager (AMCPM-TVL) to quantify the stability limits of M1037 Mobile Subscriber Equipment (MSE) payload vehicle pulling the M101 trailer. The M1037 is a the shelter carrier version of the High Mobility Military Wheeled Vehicle (HMMWV). The M101 is the utility trailer that is normally used with the M151 vehicle. The Gross Vehicle Weight (GVW) of the M1037 vehicle and M101 trailer considered in this study with the MSE payload were 8,800 lb and 3,160 lb respectively.

AMCPM-TVL requested the study because there has been concern from the test and user communities that the M1037/M101 system may not have adequate control and handling properties. Recent accidents with the M1037/M101 system at Aberdeen Proving Grounds (APG) have raised the need for the quantification of the stability limits of the system.

Dynamic simulation models of the M1037 and M1037/M101 vehicles were developed for the purpose of studying the system's dynamic behavior. The general purpose computer program Dynamic Analysis and Design System (DADS) was used to generate the the M1037 and M1037/M101 dynamic simulation models. The DADS simulation model of the M1037/M101 vehicle developed for this study featured the following:

- Full six degree of freedom dynamic vehicle simulation .
- Detailed dynamic representation of the vehicle and trailer suspension systems.
- Optimal preview control driver modeling to steer the vehicle.
- Quasi-static three dimensional tire modeling.
- A simple feedback control power train modeling that propels the vehicle at a constant speed.

DADS has been used by the U.S. Army Tank-Automotive Command (TACOM) and other organizations for over five years to successfully model the dynamic response of vehicle systems. The military vehicles that have been modeled with the DADS program include the M1, and M60 tanks, Heavy Expaned Mobility Tactical Truck/Heavy Expanded Mobility Ammunition Trailer (HEMTT/HEMAT) truck/trailer , and the M113 personal carrier.

The simulation model was validated by road testing the actual vehicle system. The simulation and the test vehicle were subjected to identical constant speed lane change, steady turn, and bump

course maneuvers. Comparisons between the simulation output and test vehicle measurements showed that simulation modeling reproduced the dynamic response of the test vehicle with sufficient accuracy.

The DADS simulation model was used to evaluate the dynamic response of both vehicle systems during lane change, steady turn, and bump course maneuvers. Simulations of both the M1037 vehicle, and the M1037 vehicle towing the M101 trailer were conducted. Speeds at which vehicle instability or violent response occurred in a maneuver were isolated to within 5 miles per hour (mph). Only constant speed maneuvers were examined in this project. Simulations of braking maneuvers were not conducted.

2.0. OBJECTIVES

The objectives for this project were to:

- Develop a validated simulation model of the M1037/M101 vehicle system.
- Generate stability boundaries for standard maneuvers that will allow users of the M1037/M101 vehicle system to set safe operating limits.

3.0. CONCLUSIONS

Validation tests described in section 5.4.1 showed that the simulation model reproduced the dynamics behavior of the M1037/M101 with sufficient accuracy. The simulation model accurately reproduced both the magnitude and the shape of the actual vehicle dynamic response.

The simulation showed that the vehicle could negotiate a 100 ft by 12 ft lane change for speeds up to 60 mph without loss of control. Secondly, the vehicle could negotiate a 500 ft radius steady turn at 50 mph (0.33 g lateral acceleration) , but went unstable at 55 mph (0.40 g lateral acceleration). Third, the simulation model showed no vehicle instability for traveling downhill on a 15% slope for vehicle speeds of up to 60 mph. Finally, the vehicle did not show any stability problems on the 6 inch bump course described in Figure 5.4-2.

The addition of a 3,160 GVW M101 trailer to M1037 significantly degrades the stability of the system. Simulations described in section 5.6.2 showed that the M1037/M101 system stability limit for a 500 ft radius steady turn was bracketed between 45 mph (0.27 g lateral acceleration) and 50 mph. Moreover, the dynamic simulation presented in section 5.6.3 showed that the trailer produced a considerable amount of roll at vehicle speeds of 10 mph through 20 mph on 6 inch bump course described in Figure 5.4-2. The M1037/M101 system did however, negotiate the 100

ft by 12 ft lane change course described in Figure 5.4-1 at up to speeds of 60 mph with no problem. When the M1037/M101 was required to negotiate a lane change on a 15% down hill slope the system showed no signs of instability. However, when the slope was increased to 29% the system was only marginally stable.

4.0. RECOMMENDATIONS

The recommendations are summarized below:

- To improve system stability, the MSE payload should be moved as far forward in the vehicle as possible.
- The front tire inflation pressure of the M1037 should be raised to 30 psi for on road use. This action will improve the vehicle's on road handling proprieties.
- If stability tests are conducted with the M1037/MSE system, outriggers should be installed on both the M1037 vehicle and the M101 trailer to prevent accidental roll over.
- The dynamic performance of M101 trailer with the M1037 as the prime mover is inadequate for off road use, and only marginally stable for on road use. A new trailer that better suits the capabilities of the HMMWV system should be designed.
- The maximum off-road speed of the M1037/M101 system should be no more than 10 mph.
- Additional simulations should be conducted to determine the sensitivity of the systems dynamic response to parameter variations.

The simulation revealed that the extreme rearward fore-aft position of the M1037 payload limits the vehicle's lateral stability to between 0.33 g and 0.4 g in a steady turn. Placing the payload further forward improves the traction of the front tires by reducing lateral load transfer in the front suspension. Moreover, the simulations showed slightly better on road vehicle response with the tires inflated at 30 pounds per square inch (psi) all the way around, than with the tires inflated at normal 20 psi front, and 30 psi rear. The effect of different set of tire inflation pressures would have on the vehicle's off road performance is uncertain. Additional off road vehicle tests should be conducted to determine if inflating the front tires to 30 psi improves vehicle response.

Adding the 3,160 lb GVW M101 trailer to the vehicle reduces the overall stability of the system. The simulations showed that the trailer has a lower stability threshold than the HMMWV for both the bump course and the steady turn maneuver. In fact, the bump course simulations show that the trailer is unsuitable for off road use in rough terrain. The primary causes for the instability are the trailer's track width (10 inches less than that of the HMMWV), and inadequate jounce travel (only 2.5 inches from the static position).

Since not all possible off road driving conditions were simulated, a maximum safe off road vehicle speed can only be approximated. Simulation results for the 6 inch bump show that the vehicle is probably not safe to drive above 10 mph.

The following additional analysis should be made of the system. First, it is uncertain how sensitive the stability of the system is to parameter variations. Additional simulations should be done with at least 10% variations in vehicle center of gravity (CG) position, weight, and tire cornering properties to see if minor changes in vehicle parameters will cause significant changes in dynamic response. Second, maximum safe down hill slope for the M1037/M101 system should be better quantified. Simulations results presented so far show that the system is stable for a 15% downhill slope, but may be unstable for a 29% slope. Additional simulation runs can help isolate the maximum safe downhill slope to within a few percentage points.

The M101 trailer should be replaced with another trailer that will degrade the HMMWV's performance only minimally, and have the same roll stability and mobility abilities as the prime mover. The dynamic simulation models developed under this project should be used to develop dynamic performance specifications for future trailer purchases.

5.0. DISCUSSION

5.1. Roll/Yaw Instability

Vehicles are subjected to two classes of instability: Divergent roll behavior, i.e., vehicle roll over, and divergent yaw behavior, i.e., spin out, jackknifing or trailer swing (in the case of articulated vehicles). Generally, the directional controllability of the vehicle for a given maneuver, is determined by the mode of instability that occurs at the lowest vehicle speed.

Vehicle dynamics researchers have found that the roll stability of a vehicle negotiating a steady turn can be expressed in terms of its lateral acceleration. See reference [1]. If the lateral acceleration is below a given level, the vehicle is roll stable. Above that level it is roll unstable. Furthermore, yaw divergent behavior can in many instances produce roll divergence. A yaw divergent vehicle may produce sufficiently high levels of lateral acceleration to cause roll over.

The yaw response of articulated vehicles can be characterized by lightly damped modes that represent trailer oscillations. These modes may cause the rear unit to produce large yaw oscillations during a lane change or some other transient maneuver. The rear unit may momentary experience a level of acceleration high enough to produce roll divergent behavior. The general

phenomenon of exaggerated lateral acceleration response of the rear unit is called "rearward amplification".

5.2. Analysis/Simulation Approach

Both analytical and simulation methods can be applied to the vehicle stability problem. Dynamic simulation provides an accurate method of predicting the dynamic behavior of a vehicle for a given set of circumstances, but it does not tell how to vary the parameters of the system to correct a stability problem. Moreover it also does not provide a direct measure of the stability of the vehicle. Analytical methods, such as eigenvalue methods, can show how parameters effect the systems stability. They also show how close a particular vehicle configuration may be to being unstable. However, many simplifications must be made to a vehicle model in order to apply analytical methods. Thus, the results predicted by an analytical approach may only approximate the stability of the actual vehicle system.

In practice, simulation, analysis, and road testing can all be used in concert to solve vehicle dynamics problems. Yaw plane analysis provides course predictions on the onslaught of yaw instability, and predictions on how parameters affect vehicle stability. Spatial vehicle simulations provide finer predictions then yaw plane analysis, but more situations must be evaluated to produce the stability boundary. Finally, road testing provides a means for gaining confidence in the predictions generated from the simulation and the analytical models.

5.3. The Simulation Model

DADS [2,3] was used to model the dynamic behavior of the M1037 vehicle and M101 trailer system. DADS is a general purpose computer program that simulates the dynamic behavior of spatial multibody mechanical systems. It can model the dynamic response of both rigid and flexible systems, and it uses a library of joints and constraints to model the kinematics of the mechanism. The user assembles a dynamic model of vehicle with a language that consists of bodies, joints, constraints, and force elements. This capability minimizes the amount of equation derivation and computer programing the must do to develop a dynamic simulation model. Thus, the dynamics of a complex mechanical system can be modeled in the fraction of the time which would be required if the equations of motion were developed manually.

5.3.1. The Truck Simulation Model

The M1037 vehicle model is documented in a report by Aardema [4], therefore only a brief description of the model will be provided. Figure 5.3.1-1 shows the M1037 system and Table 5.3.1-1 provides a summary of significant parameters and overall dimensions used in the

simulation model. The standard DADS rigid body and joint constraint elements that were used to model the kinematic and dynamic structure of the vehicle are shown in Table 5.3.1-2. A schematic representation for the vehicle that shows how the rigid body elements in the simulation model are interconnected is provided in Figure 5.3.1-2. Figures 5.3.1-3 through 5.3.1-11 show top and side views of the HMMWV vehicle front and rear suspensions.

Table 5.3.1-1 Vehicle parameters used for the vehicle and trailer simulation.

Description	Value
Truck Weight	8800 lb
Truck Roll Inertia	13320 in-lb-s^2
Truck Pitch Inertia	52680 in-lb-s^2
Truck Yaw Inertia	56280 in-lb-s^2
Truck center of gravity height	50.0 in
Distance between truck CG and front wheels	83.8 in
Distance between truck CG and rear wheels	46.2 in
Distance from truck rear axle to trailer hitch	37.5 in
Wheel base of truck	130.0 in

Table 5.3.1-2 Element types used in M1037 simulation model.

Vehicle Component	Element Type Used in Model
Chassis	Rigid body
Upper & lower control arms	Rigid body
Pitman Arm	Rigid body
Wheel hub	Rigid body
Upper & lower ball joints	Spherical joint
Steer Link, and tie rods	Spherical - spherical joint
Rear rad arms	Spherical - spherical joint
Chassis/control arm connection	Revolute Joint
Springs, shocks	Translational spring damper actuator
Tire	Specially developed software
Driver model	Specially developed software
Power train	Specially developed software

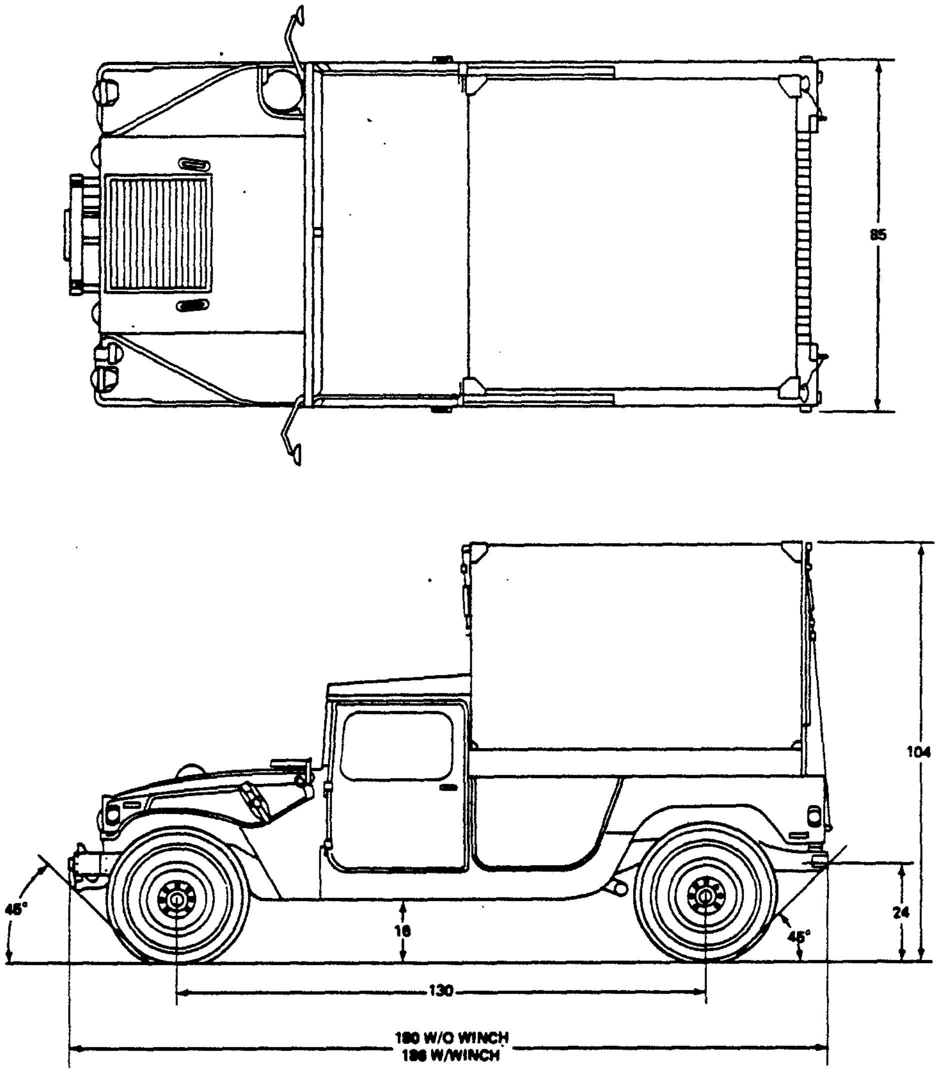

Figure 5.3.1-1 The M1037 truck.

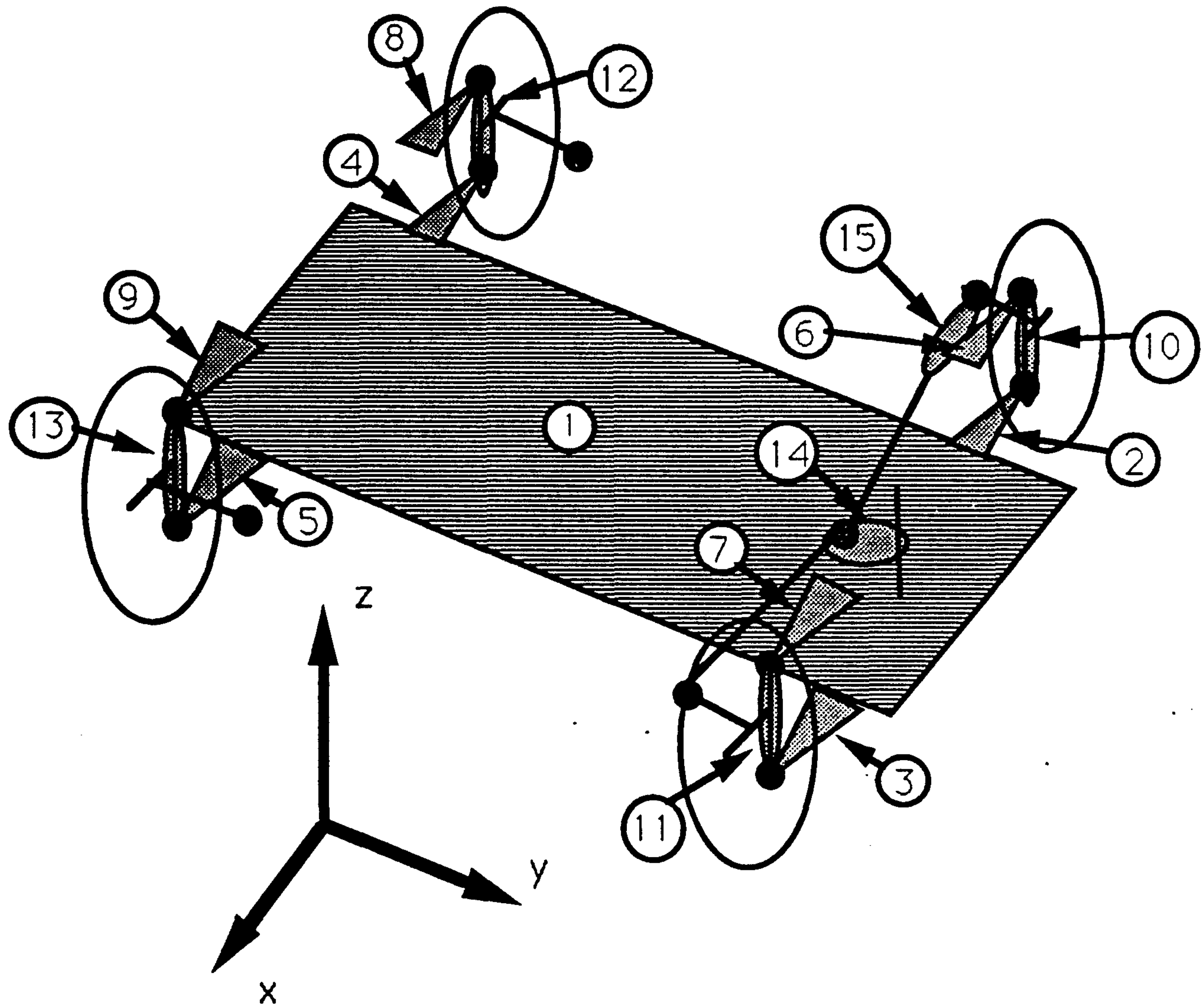

Figure 5.3.1-2 Schematic representation for the M1037 truck.

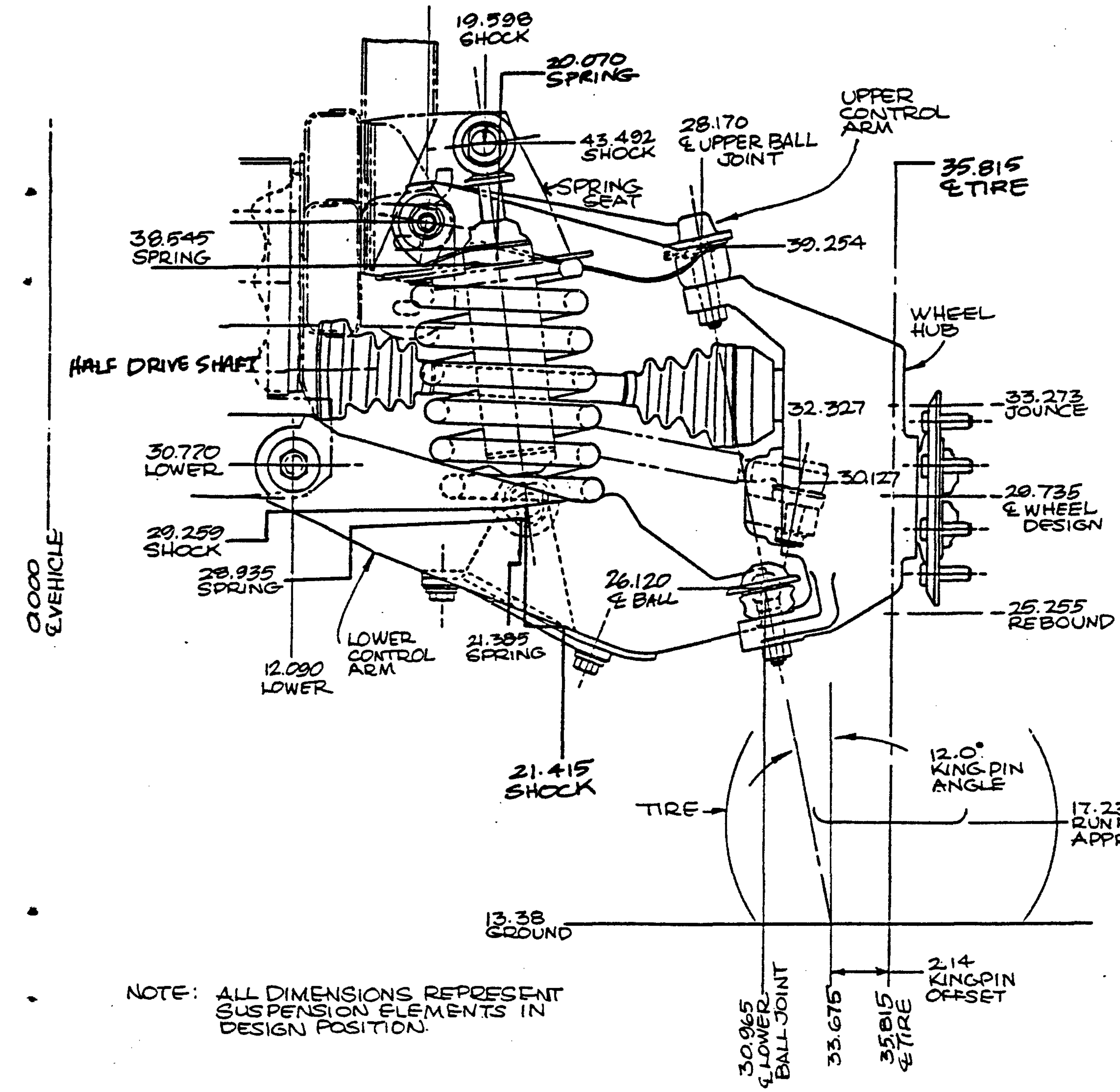

Figure 5.3.1-3 The M1037 front left suspension, front view.

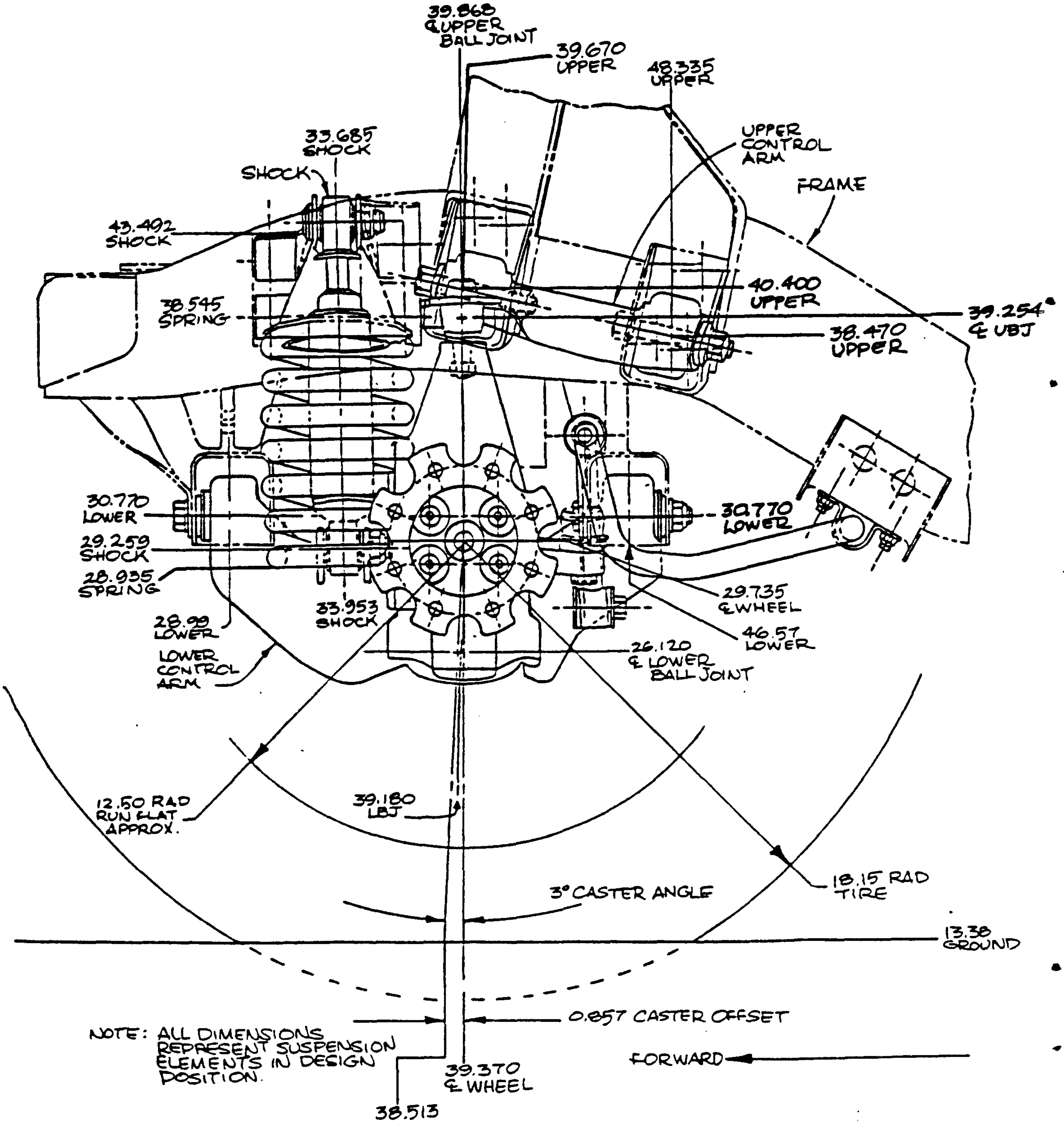

Figure 5.3.1-4 The M1037 front left suspension, left side view.

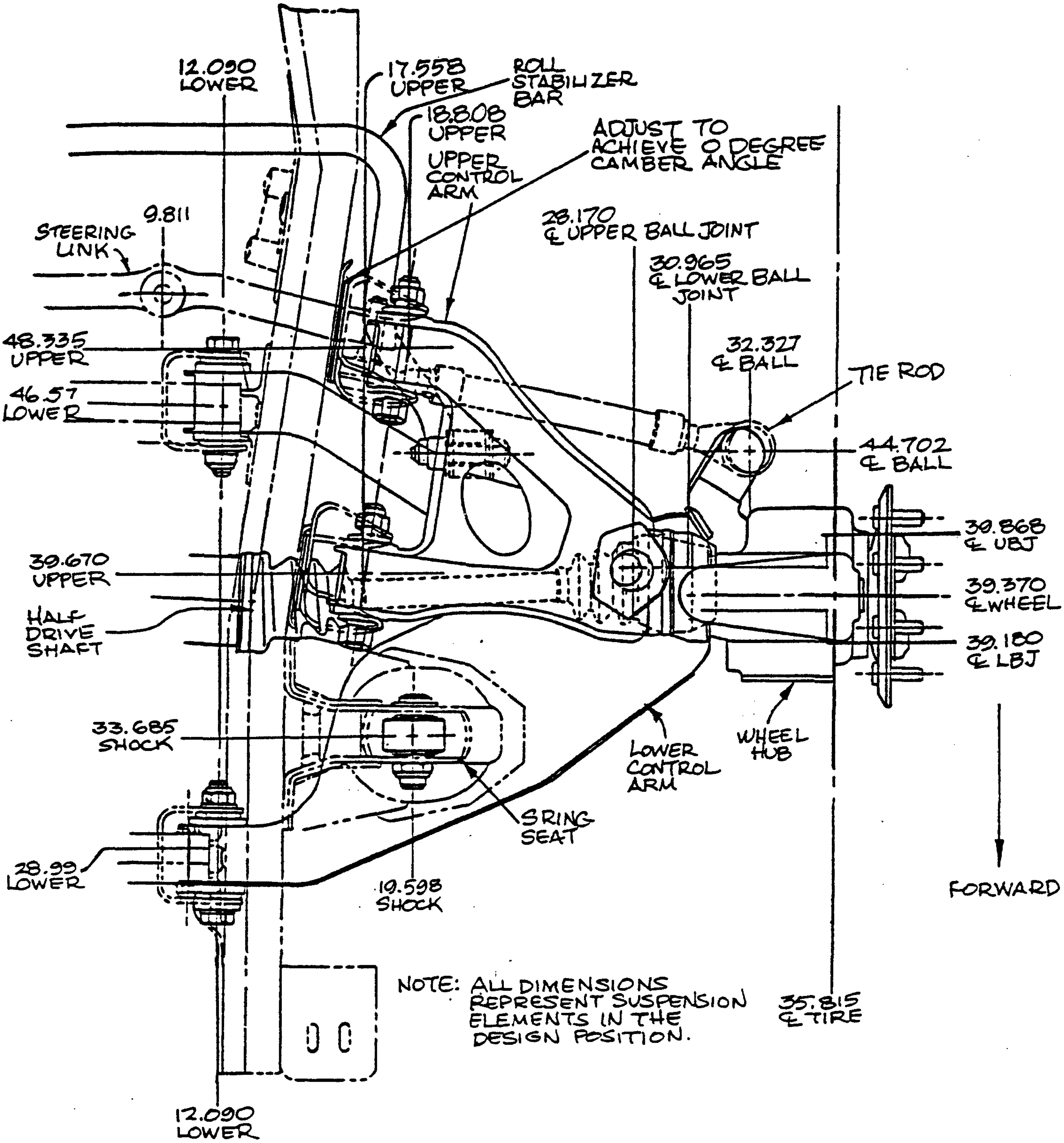

Figure 5.3.1-5 The M1037 front left suspension, top view.

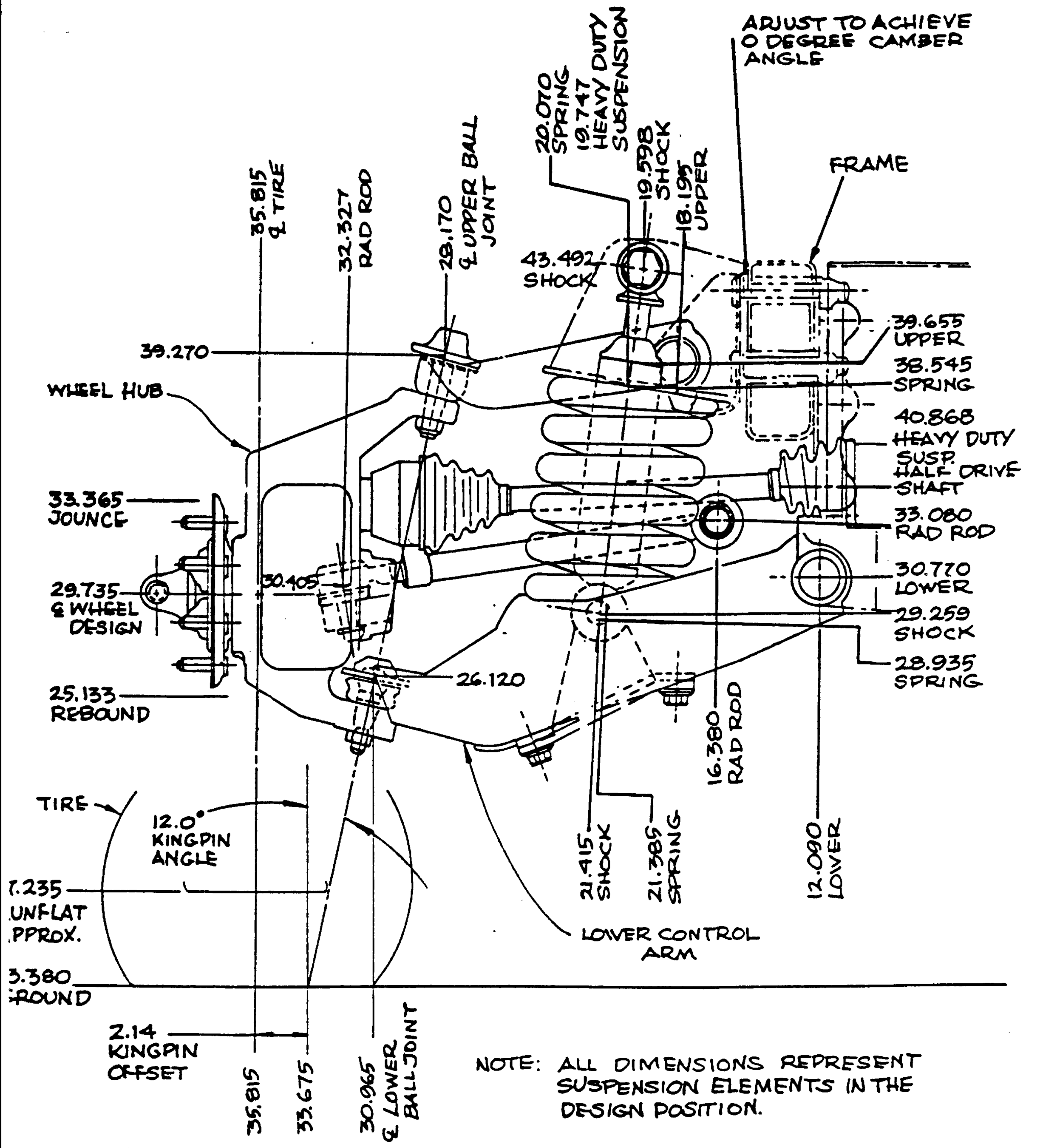

Figure 5.3.1-6 The M1037 rear left suspension, rear view.

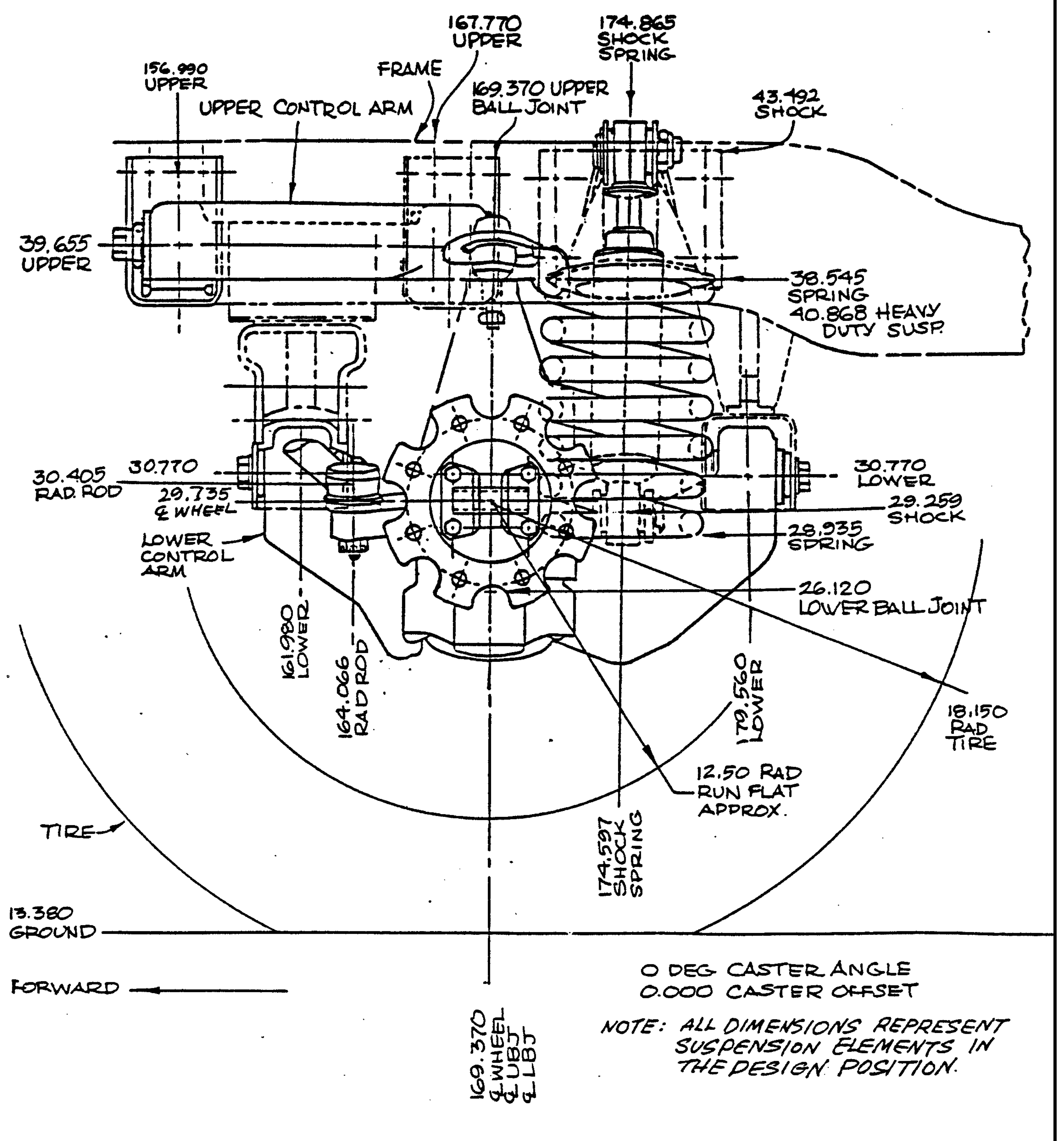

Figure 5.3.1-7 The M1037 front left suspension, left side view

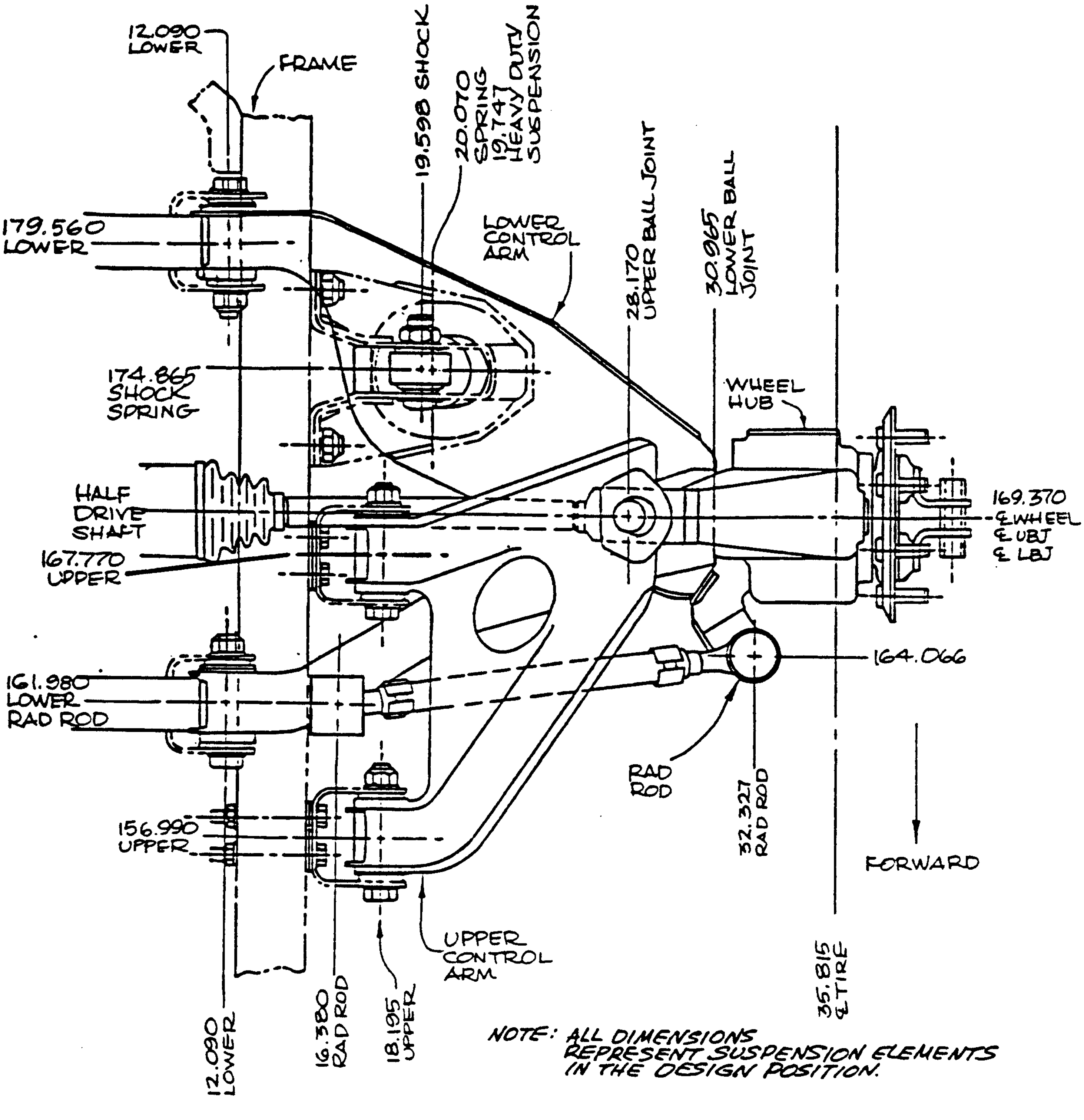

Figure 5.3.1-8 The M1037 rear left suspension, top view

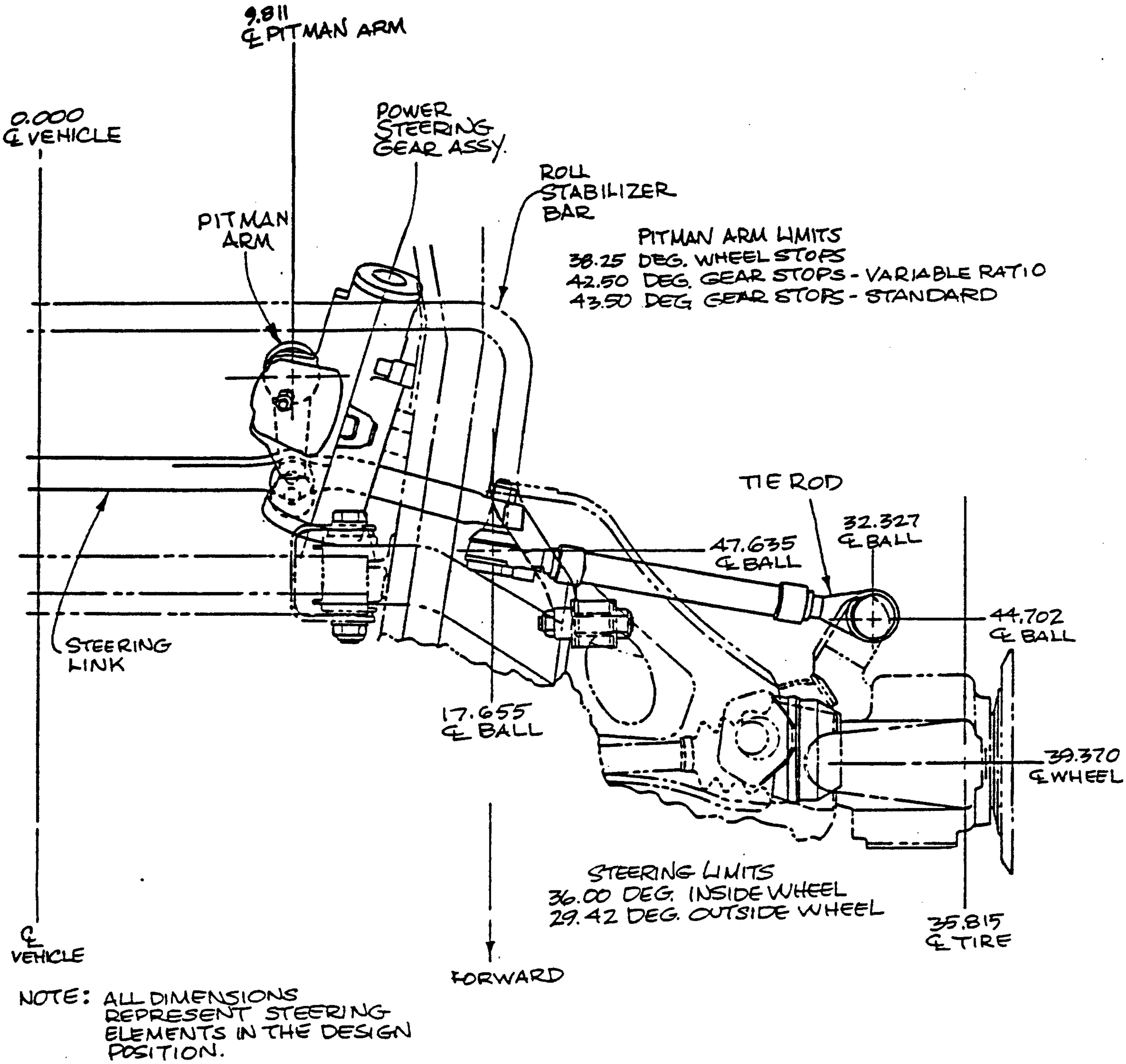

Figure 5.3.1-9 The M1037 steering left side, top view

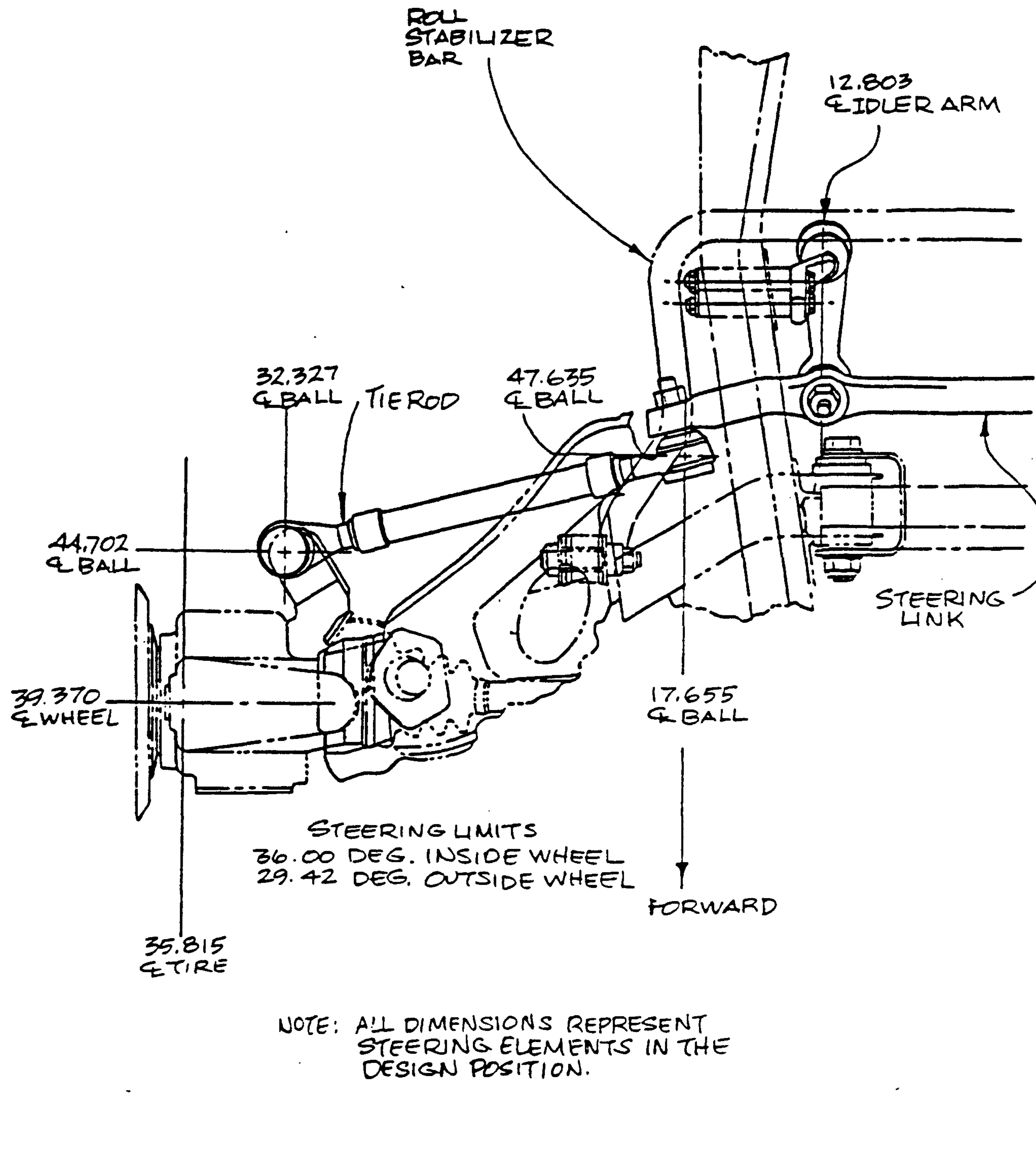

Figure 5.3.1-10 The M1037 steering right side, top view

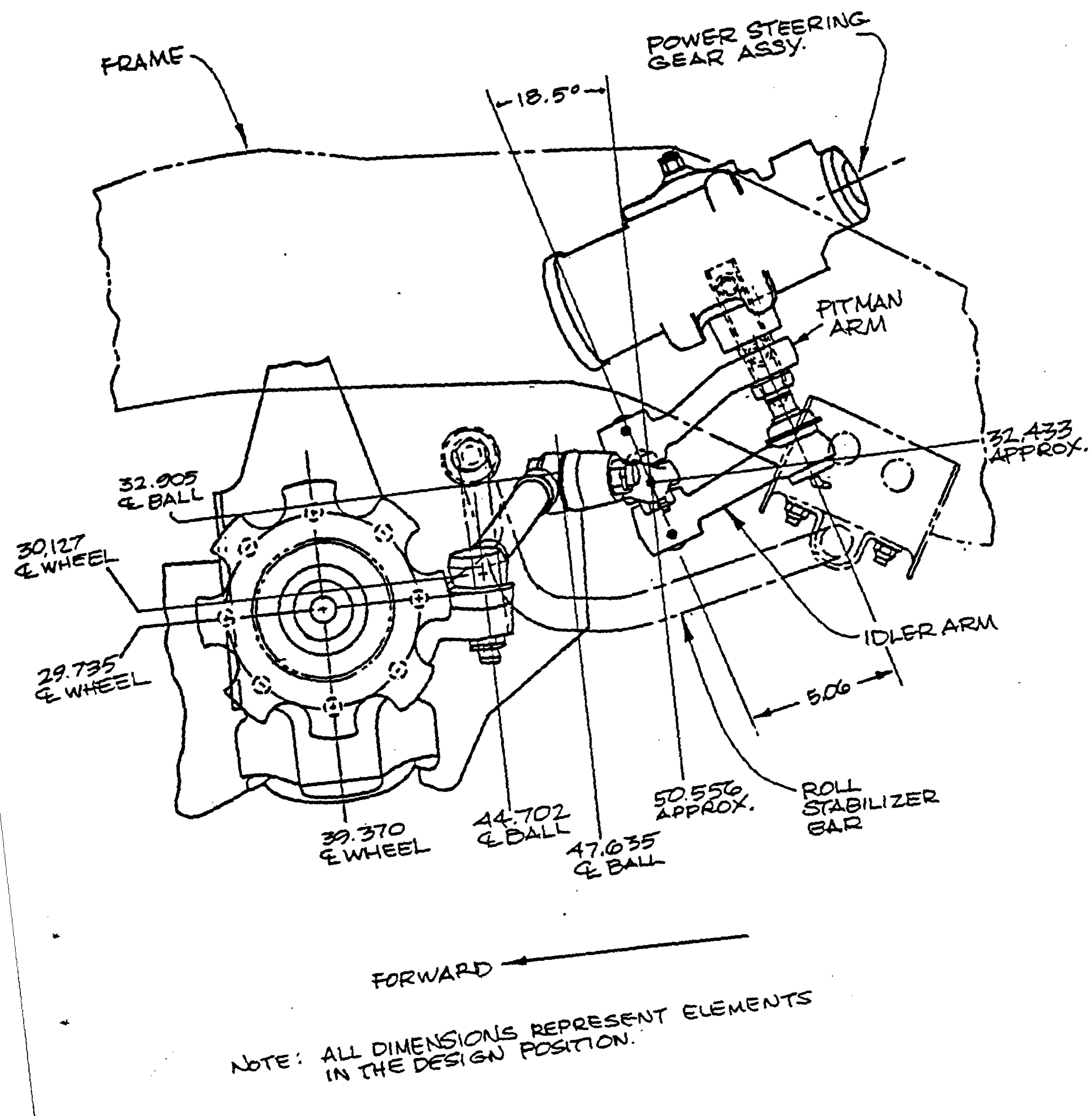

Figure 5.3.1-11 The M1037 steering, left side view

5.3.2. Trailer Simulation Model

Figure 5.3.2-1 shows the M101 trailer, and Table 5.3.2-1 shows pertinent dynamic and dimensional parameters used in the trailer simulation model. Table 5.3.2-2 shows simulation elements used to model the trailer components and Figure 5.3.2-2 shows a schematic of the connectivity of the rigid bodies.

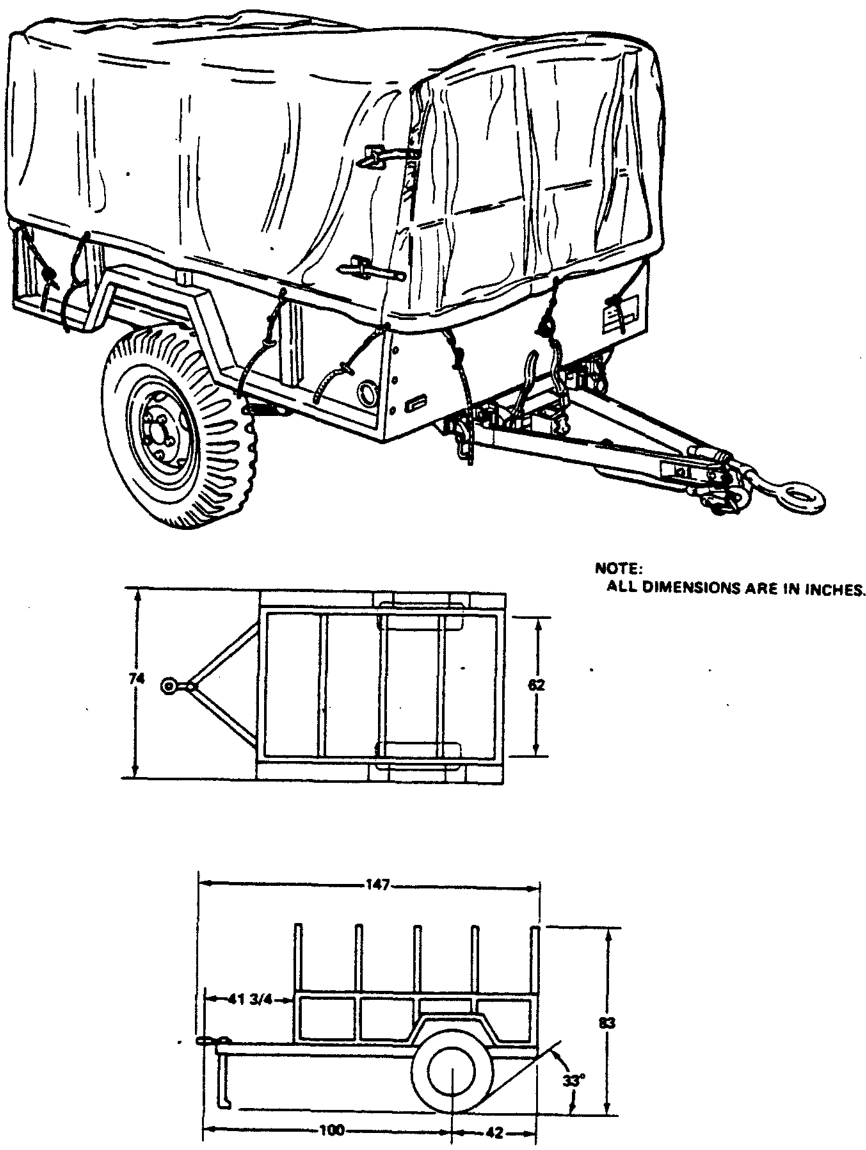

Figure 5.3.2-1 The M101 trailer.

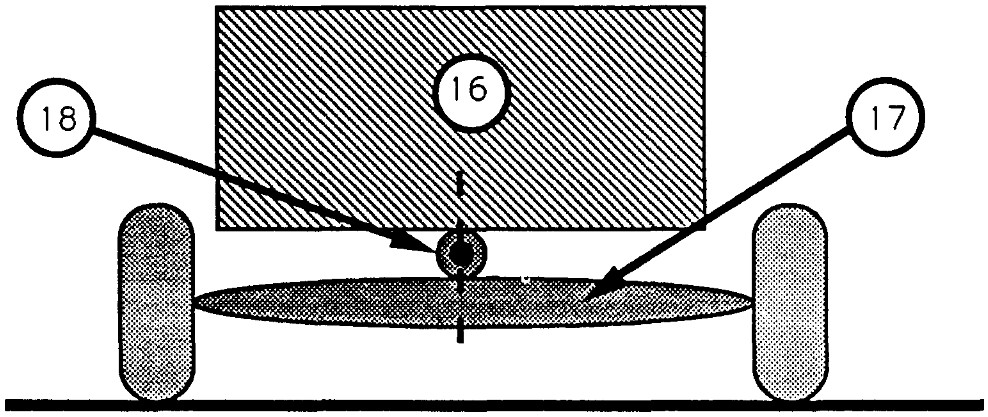

Figure 5.3.2-2 Schematic representation of the M101 trailer.

Table 5.3.2-1 Vehicle parameters used for the M101 simulation model.

Description	Value
Trailer Weight (GVW)	3160 lb
Trailer Roll Inertia	2600 in-lb-s^2
Trailer Pitch Inertia	10000 in-lb-s^2
Trailer Yaw Inertia	10000 in-lb-s^2
Trailer center of gravity height	41.2 in
Distance from trailer CG to hitch	95.65 in
Distance from trailer CG to axle	3.35 in
Distance from trailer CG to hitch	99.0 in
Trailer hitch load	176 lbf

Table 5.3.2-2 Element types used in the trailer simulation model.

Vehicle Component	Element Type Used in Model
Chassis	Rigid body
Axle	Rigid body
Suspension	Rigid body, trans and rev joints
Auxiliary roll stiffness	Rotary spring, damper actuator (RSDA)
Trailer hitch	Spherical joint
Tires	Specially developed software

Figures 5.3.2-3 and 5.3.2-4 show respectively, the damping and load characteristics used in the simulation model. The leaf spring is assumed to have constant spring rate deflections between the jounce and rebound stops. For penetration of the jounce and rebound stops, the effective spring rate is increased by a factor of 10. When the trailer rotates relative to the axle it twists the leaf springs producing a moment that resists roll. This phenomenon can be modeled as a moment that is proportional to the relative rotation of the trailer chassis and axle. This moment is applied with equal and opposite signs to the trailer chassis and axle. The constant of proportionally is also known as auxiliary roll stiffness. Since M101 suspension system has not been characterized, the value of trailer auxiliary roll stiffness was not available, so a value of 10% of the vertical spring rate was estimated. This value is typical of small trailer leaf spring suspensions.

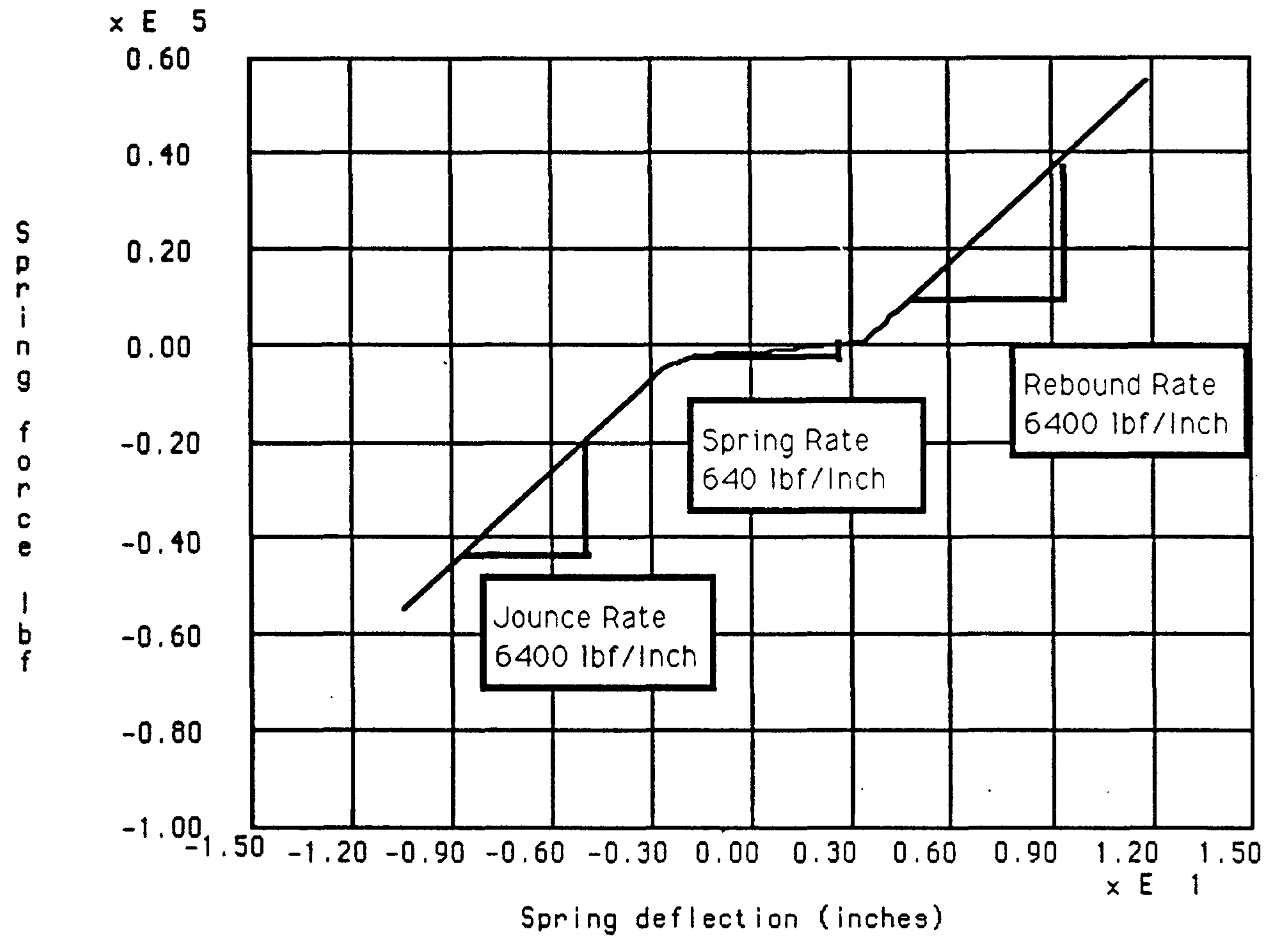

Figure 5.3.2-3 Force deflection characteristics of the M101 trailer leaf spring.

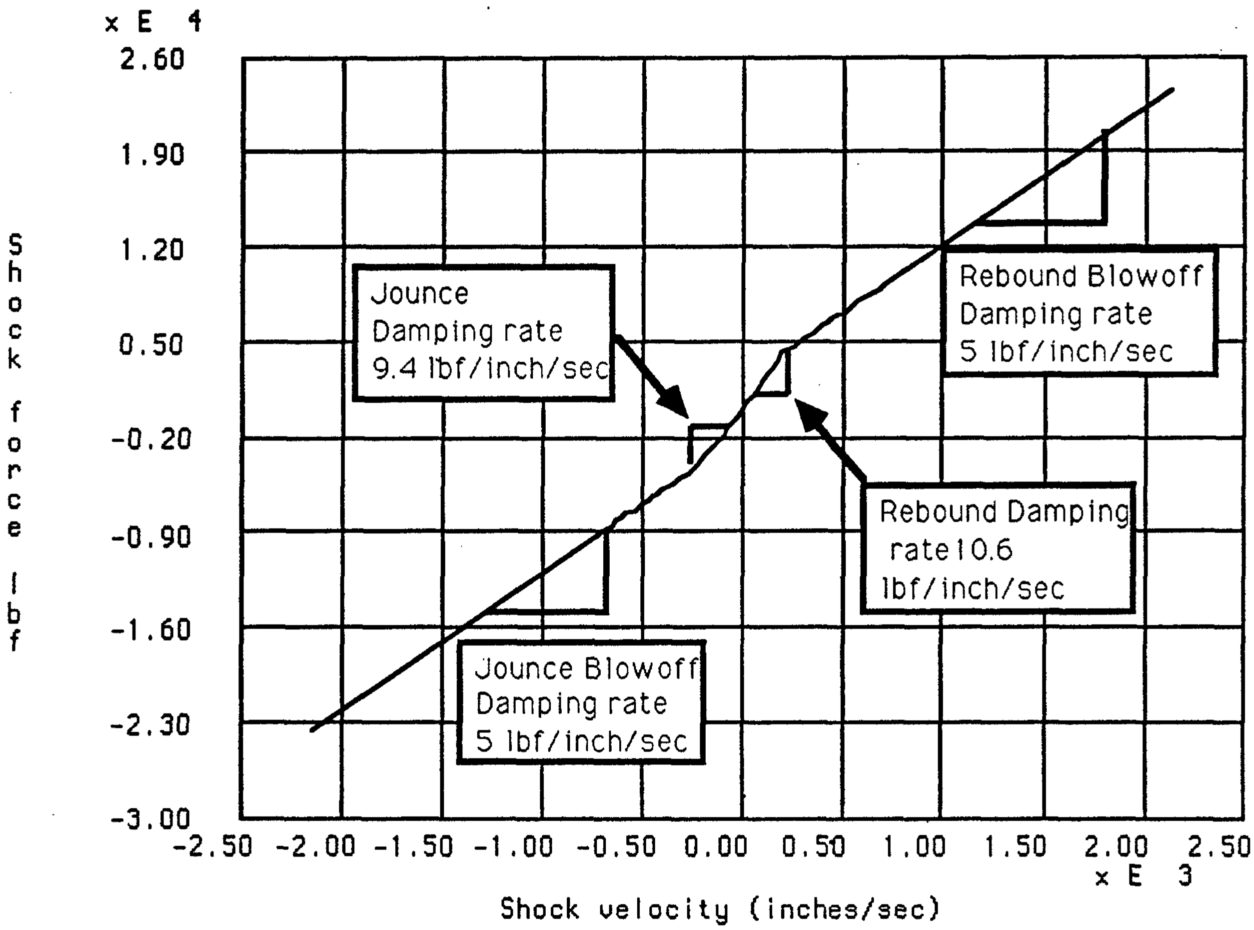

Figure 5.3.2-4 Damping characteristics of M101 shocks

5.3.3. The Tire Model

The dynamics of the tire during vehicle on road operation is represented by a semi-empirical model, primarily based upon work performed by Bergman [5], Dugoff, et. al. [6]. The block diagram in Figure 5.3.3-1 indicates the tire model flow of control. The model calculates the lateral and longitudinal slip, vertical tire deflection and drive torque in the FORTRAN subroutine FRC38. The subroutine TIREF calculates the tire lateral, longitudinal, and vertical forces, and aligning moment. The model assumes that the lateral force and aligning moment is a function of both lateral slip and vertical tire load. Tire cambering effects are not considered in the model. A friction circle model limits the tractive forces (lateral and longitudinal) acting upon the tire. The forces and moments are applied to the wheel hub in the manner shown in Figure 5.3.3-2.

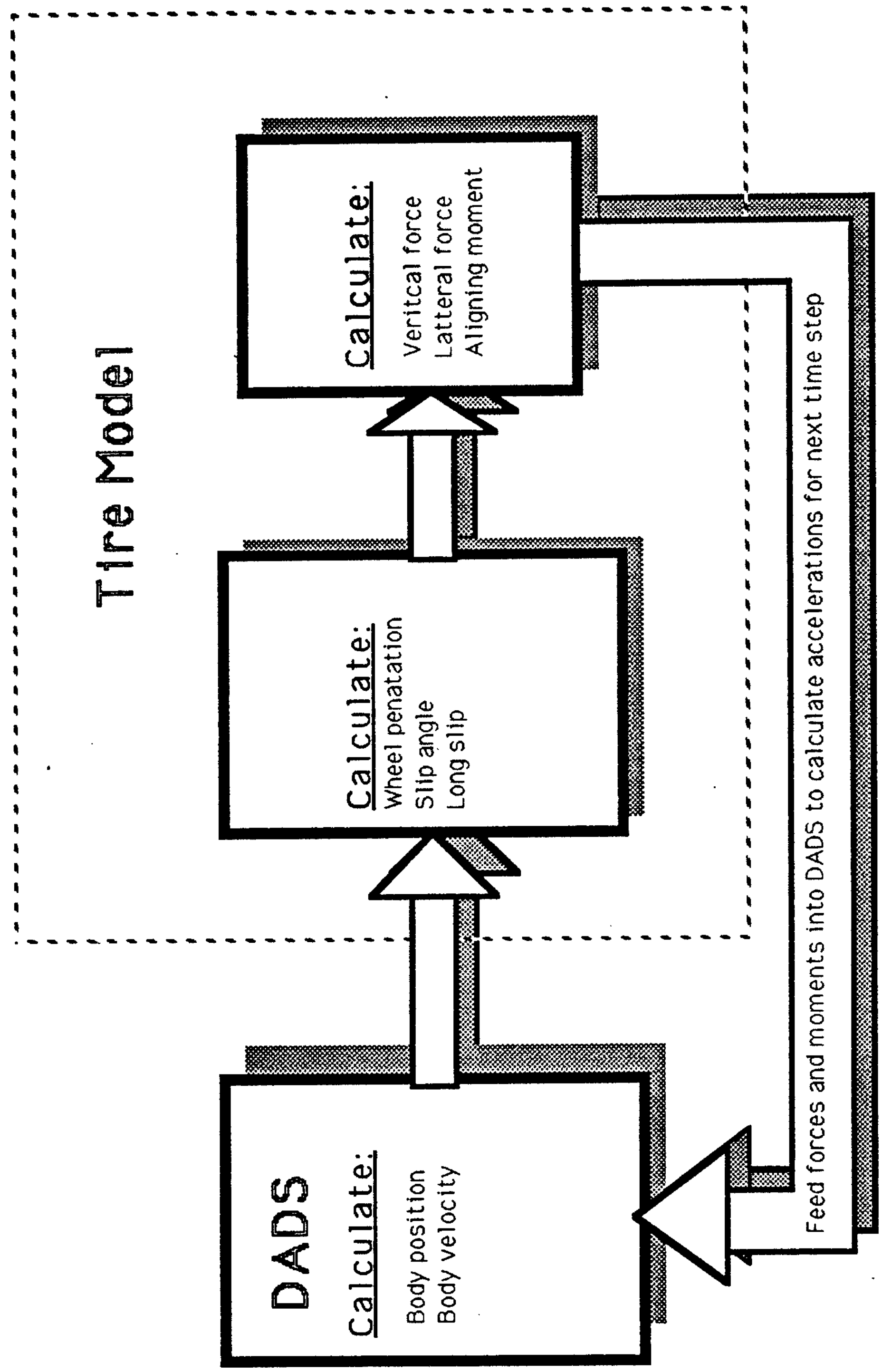

Figure 5.3.3-1 The flow of control for tire model

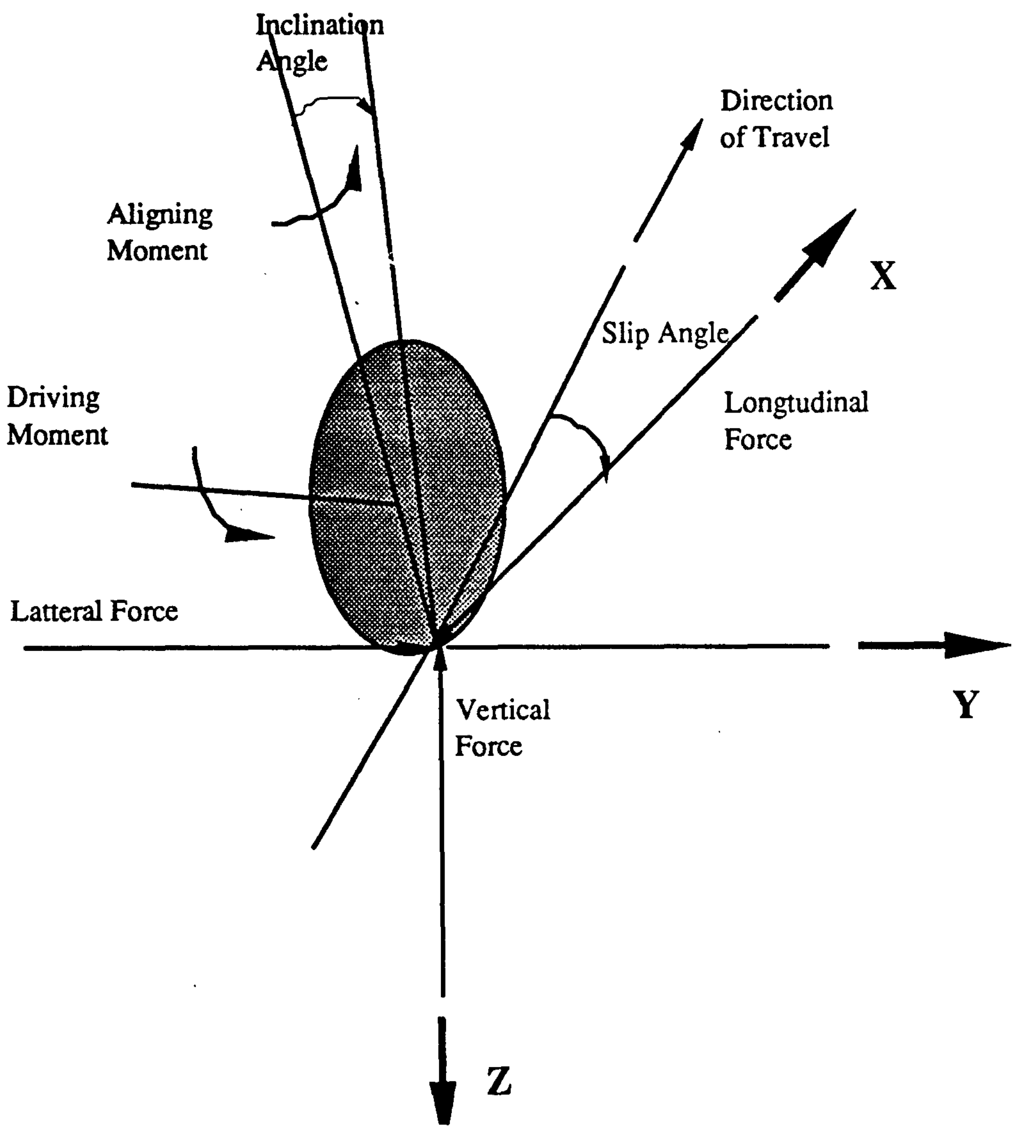

Figure 5.3.3-2 The forces and moments acting upon a tire

The lateral force/slip and aligning moment/slip data for the M1037 vehicle and M101 trailer tires is shown in figures 5.3.3-3 through 5.3.3-6. The 36x12.50-16.5 LT tire used on the HMMWV vehicle was measured by the University of Michigan Transportation Research Institute (UMTRI). These measurements were performed on a flat bed testing machine at tire inflation pressures of 20 psi and 28 psi. Measured test data was not available for the LT235/85R16 tire specified for the M101 trailer. However, tire lateral force/slip and aligning moment slip data for a 8.75R16.5 tire, which is close in configuration to the LT235/85R16 tire was available in reference [7]. Figure 5.3.3-7 shows the longitudinal force data used for both the M1037 vehicle and M101 trailer tires. The data in Figure 5.3.3-7 was generated from descriptions of average tire properties provided in reference [7].

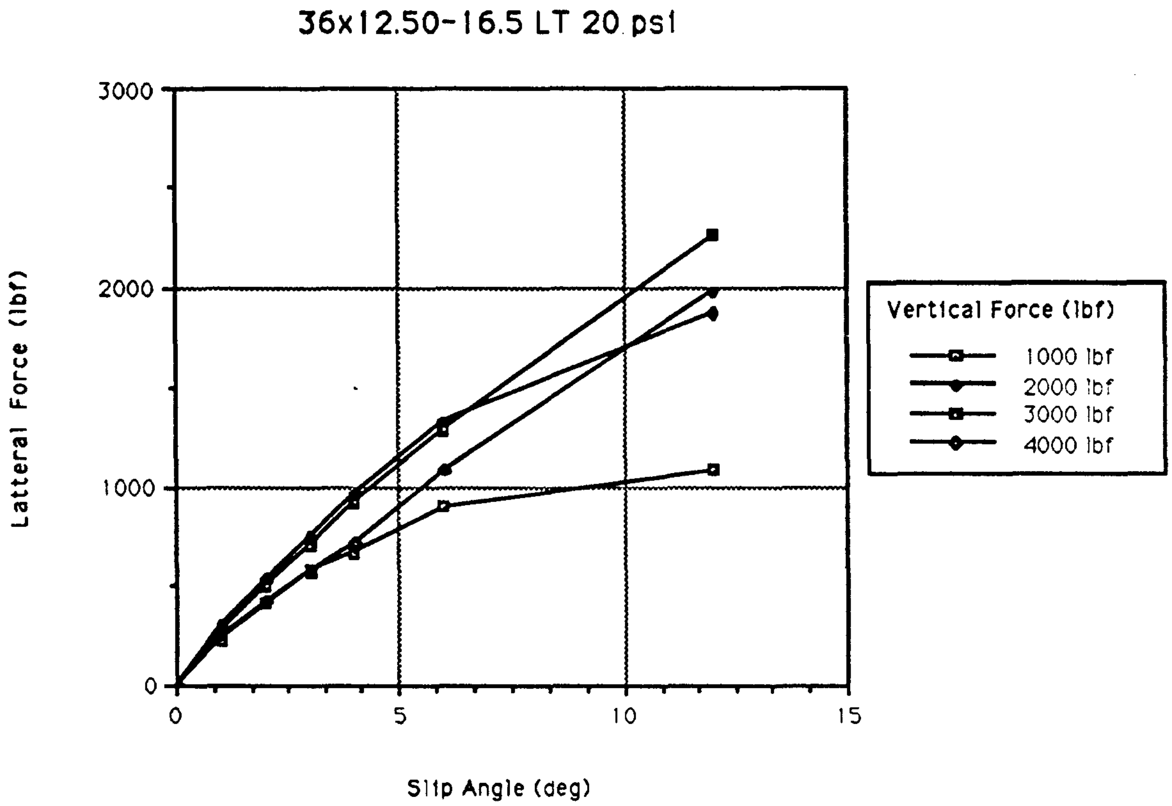

Figure 5.3.3-3 The trailer tire lateral force versus slip data for the 36x12.50-16.5LT tire at 20 psi

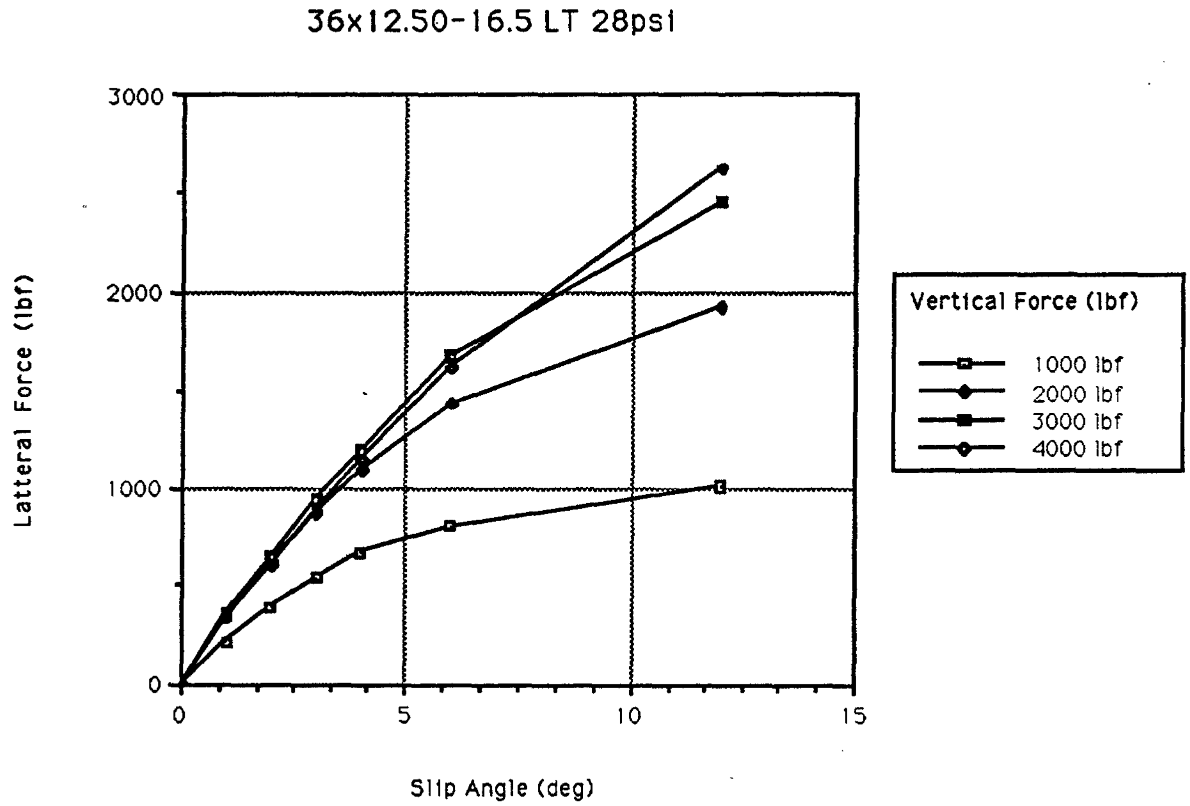

Figure 5.3.3-4 The trailer tire lateral force versus slip data for the 36x12.50-16.5LT tire at 28 psi

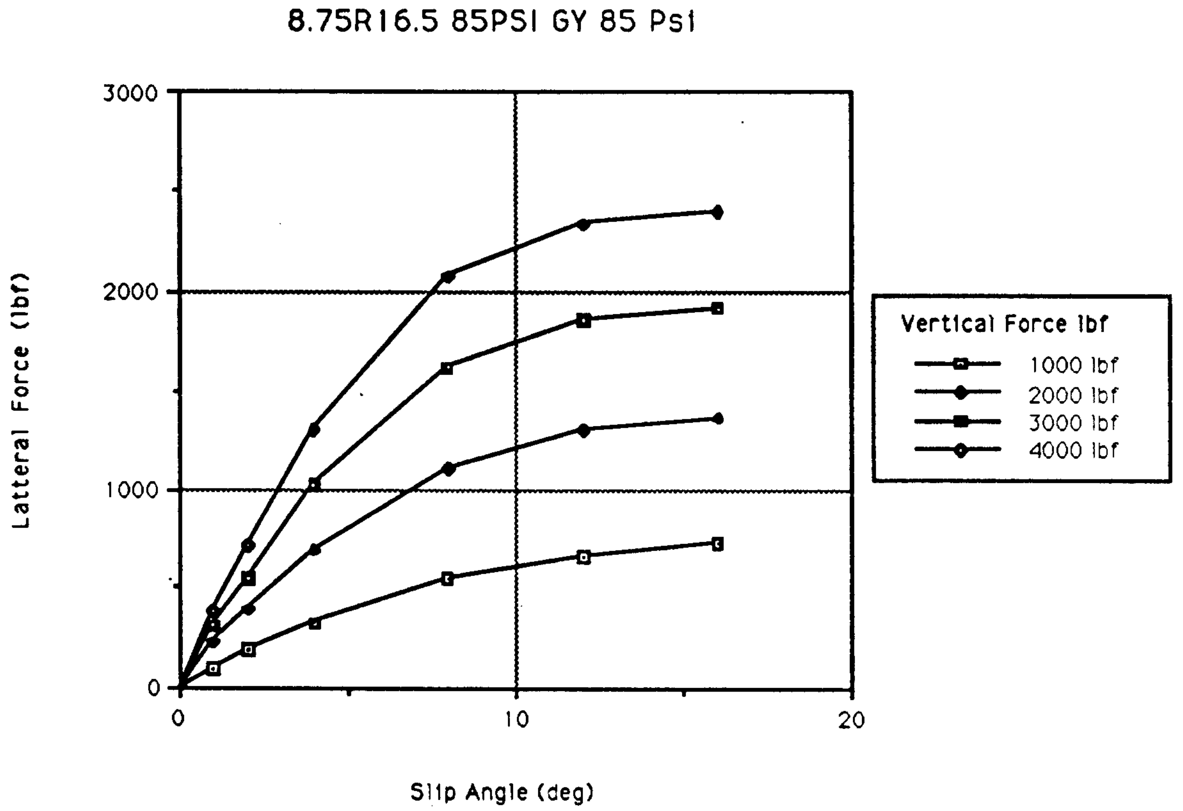

Figure 5.3.3-5 The trailer tire lateral force versus slip data

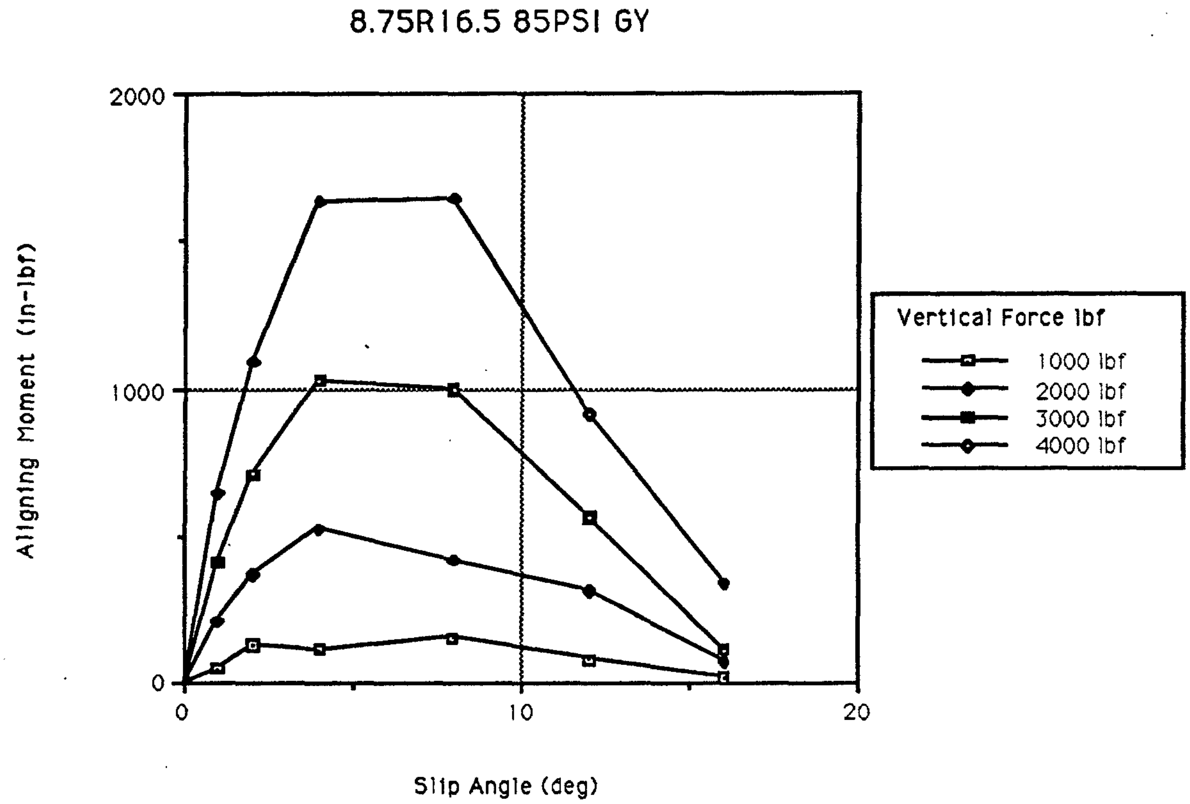

Figure 5.3.3-6 The trailer tire aligning moment versus slip data

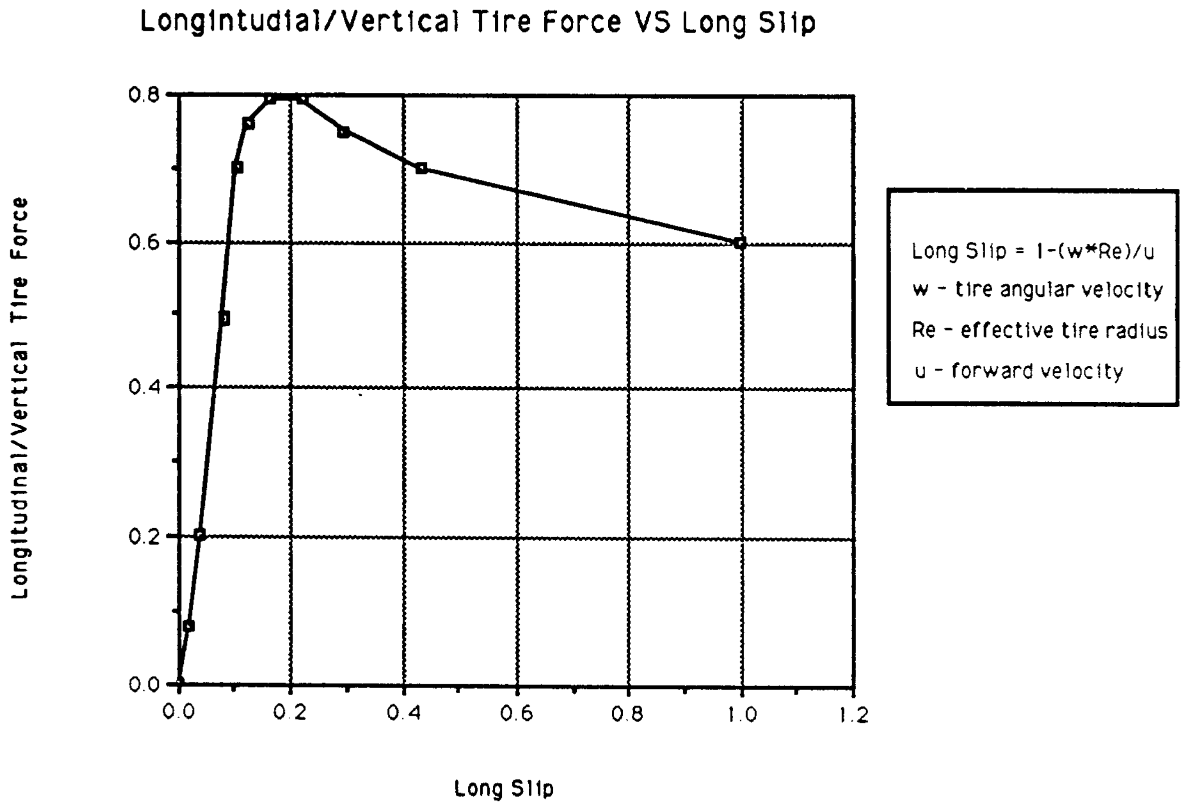

Figure 5.3.3-7 The trailer tire longitudinal/vertical force versus longitudinal slip data.

5.3.4. The Driver Model

Realistic simulation of vehicle systems requires an adequate representation of driver dynamics. A driver during normal driving conditions is required to:

- Navigate the vehicle through a roadway.
- Reject wind and ground disturbances acting upon the vehicle.
- Maintain system stability and compensate for the vehicle's nonlinear behavior and dynamic deficiencies.

The above requirements compare to those of a feedback control system. See Figure 5.3.4-1. The driver and vehicle respectively fulfil the basic requirements of a control and the plant.

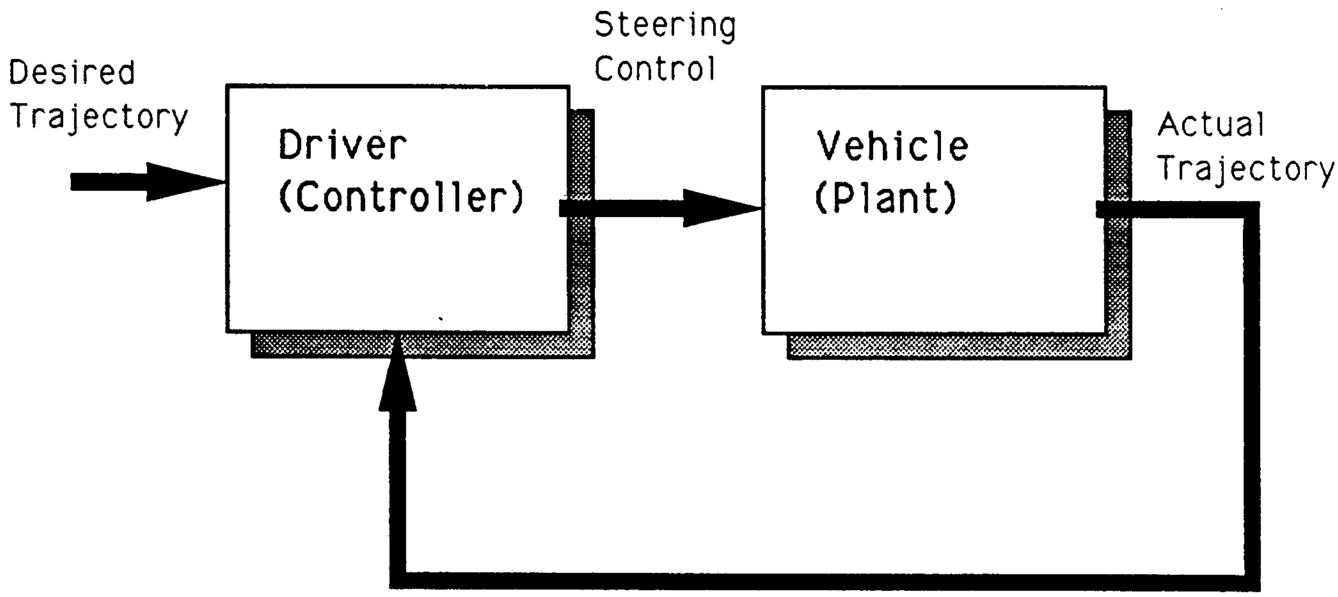

Figure 5.3.4-1 Driver control strategy.

Measurements performed on human drivers over the past 30 years revealed they maintain certain closed loop dynamic properties. First, a human operator will maintain a 20 decibel (dB) per decade slope through the region cross over frequency ω_c . See Figure 5.3.4-2. Furthermore, McRuer [8] has shown the the transport delay of τ seconds represents a good approximation of the dynamic behavior of the driver at frequencies below ω_c . At higher frequencies, neither of the approximations provide adequate representation for the dynamic response of the driver. However, the plant transfer function rolls off in this region enough to have little effect on system response. The bottom line is this: for any model to adequately represent the dynamics of the driver, it must produce a 20 dB per decade drop in closed loop response in the region of the cross over frequency and must approximate a time delay of τ seconds.

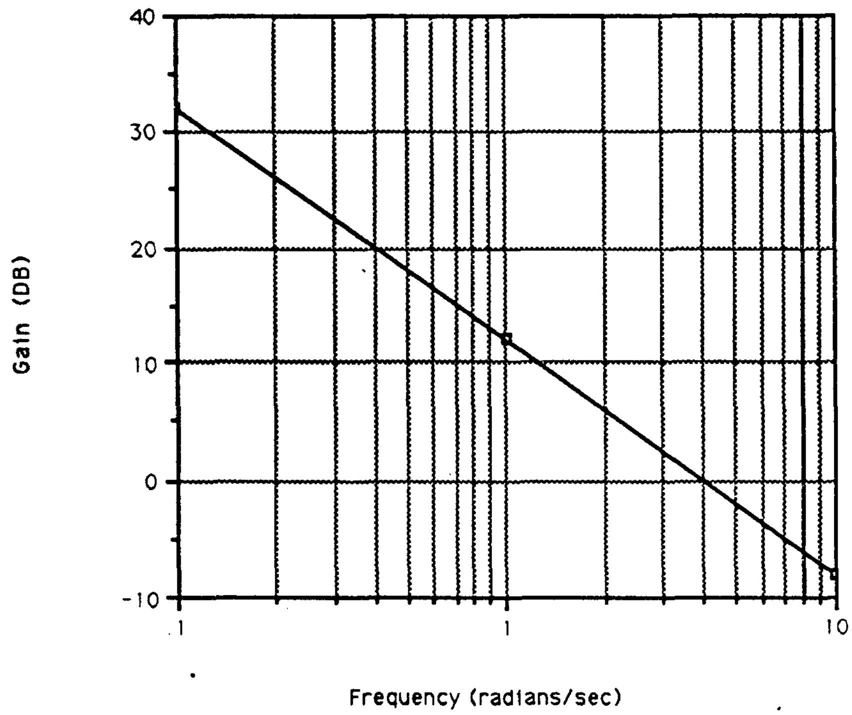

Figure 5.3.4-2 Closed loop frequency response gain (from Ref. 9)

An optimal preview control method, developed by MacAdam [9,10], was adapted for this analysis to model the dynamic behavior of the driver. In this approach, it is assumed that a well trained driver employes a preview control strategy to control the vehicle. See Figure 5.3.4-3. The optimal steering control is determined from minimizing the performance measure

$$J = \frac{1}{T}\int_{t}^{t+T}\left\{\left[f(\eta) - y(\eta)\right]^2 \mathbf{W}\,(\eta - t)\right\} d\eta \tag{5.3.4-1}$$

and the constraints

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{F}\,\mathbf{x} + \mathbf{g}\mathbf{u} \\ y &= \mathbf{m}^T\mathbf{x} \end{aligned} \tag{5.3.4-2}$$

J in equation (5.3.4-1) represents the mean square preview error, and equation (5.3.4-2) is a linearized representation of the yaw plane vehicle dynamics. The matrix[1] **W** is an arbitrary weighting matrix.

[1] In this report, matrices and vectors will be printed in bold type.

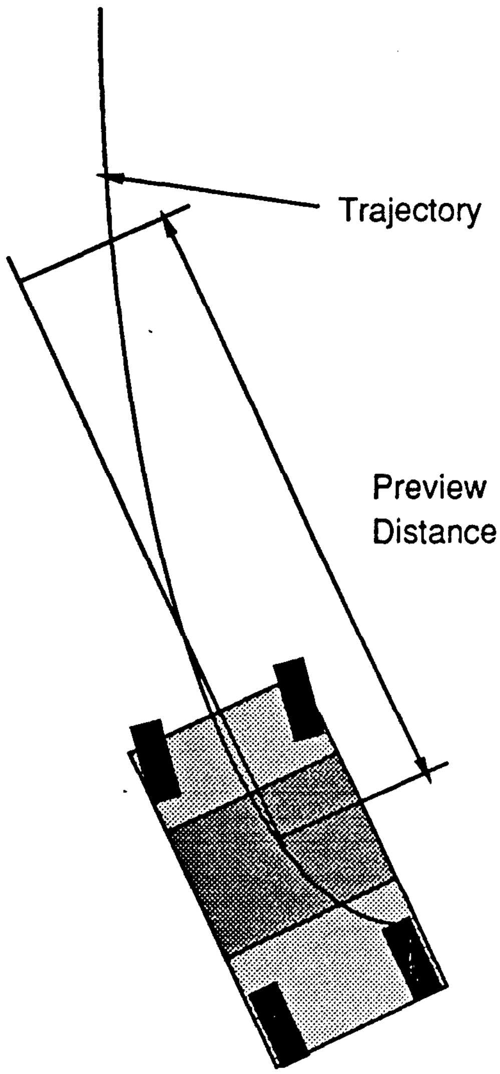

Figure 5.3.4-3 Preview control strategy

For the special case where W (η - t) = δ (T^*), the Dirac delta function, the optimal control was derived in [9] to be

$$u^*(t) = u(t) + \frac{\varepsilon(t+T^*)}{T^* K} \tag{5.3.4-3}$$

where

$$K = \mathbf{m}^T \left[\mathbf{I} + \sum_{n=1}^{\infty} \frac{\mathbf{F}^n (T^*)^n}{(n+1)!} \right] \mathbf{g}$$

and u (t) is the current system input and ε ( ) is the preview output error, defined as:

$$\varepsilon(\eta) = f(\eta) - \mathbf{m}^T \Phi(\eta, t)\, x(t) - u(t)\, A(\eta) \tag{5.3.4–4}$$

where Φ is the state transition matrix for equation 2.2

$$\Phi(\eta, t) = \mathbf{I} + \sum_{n=1}^{\infty} \frac{\mathbf{F}^n (\eta - t)^n}{n!}$$

and

$$A(\eta) = (\eta - t)\, \mathbf{m}^T \left[\mathbf{I} + \sum_{n=1}^{\infty} \frac{\mathbf{F}^n (\eta - t)^n}{(n+1)!} \right] \mathbf{g}$$

The block diagram in Figure 5.4.3-2 shows the control strategy for the single point feedback steering control system.

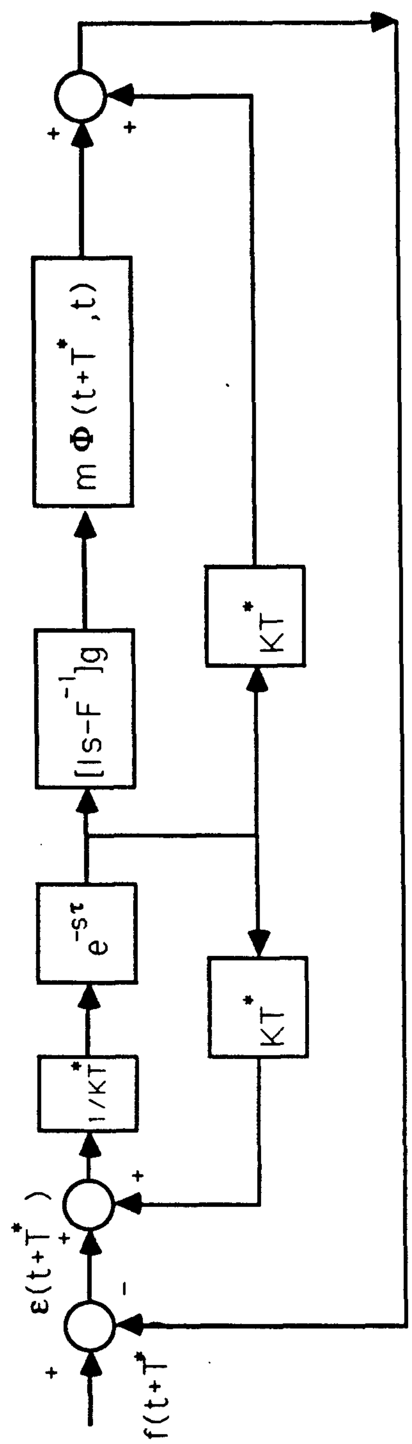

Figure 5.3.4-2 Single point preview control block diagram.

The feedback control gain matrix $\mathbf{c}^T$ is given by

$$\mathbf{c}^T = \mathbf{F} - \left\{ \mathbf{g}\mathbf{m}^T \left[\mathbf{I} + \sum_{n=1}^{\infty} \frac{\mathbf{F}^n (\eta)^n}{(n+1)\,!} \right] \right\} \Big/ (\mathbf{T}^* \mathbf{K}) \qquad (5.3.4\text{-}5)$$

The state space representation for the feedback control system including the driver transport lag τ, is given by

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{F}\,\mathbf{x} + \mathbf{g}\,u^o(t - \tau) \\ u^o &= -\,\mathbf{c}^T \mathbf{x} \end{aligned} \qquad (5.3.4\text{-}6)$$

If the driver transport lag is approximated by a first order Padé polynomial

$$\frac{1 - \frac{\tau}{2} s}{1 + \frac{\tau}{2} s}$$

then the closed loop state equations become,

$$\begin{Bmatrix} \dot{\mathbf{x}} \\ \dot{u} \end{Bmatrix} = \begin{bmatrix} \mathbf{F} & \mathbf{g} \\ \mathbf{c}^T\left(\mathbf{F} - \frac{2}{\tau}\mathbf{I}\right) & \mathbf{c}^T\mathbf{g} - \frac{2}{\tau} \end{bmatrix} \begin{Bmatrix} \mathbf{x} \\ u \end{Bmatrix} \qquad (5.3.4\text{-}7)$$

Thus, the system is stable if all the eigenvalues of the matrix in equation (5.4.3-7) lie in the left hand plane.

MacAdam [7] has shown that the driver controller strategy described above has the two closed loop dynamic properties described in the start of this section. The closed loop response of the vehicle has a 20 db per decade slope through the cross over frequency, and a time delay of τ seconds.

Two parameters in the driver model, the time delay τ, and preview time T have a significant effect on the dynamic response of the system. When the value of τ is increased the system becomes more oscillatory, or less stable. When the value of T is increased the system has a more damped response. These parameters actually characterize the performance of the driver. A skillful driver will have a small value of τ while an impaired driver will have a large value of τ. Typical ranges of values for τ and T for well trained drivers are respectively 0.1-0.3, and 1.0 - 2.0 .

5.3.5. Implementation of the Driver Model

The block diagram in Figure 5.3.5-1 shows the driver model is interfaced to the DADS program. Steering of the vehicle is accomplished with a constraint element between the pitman arm and chassis rigid bodies. The constraint element controls the rotation of the pitman arm. The FORTRAN subroutine USER49 provides the means of interfacing the driver model software to the DADS code. USER49 has access to the position and velocity of each rigid body in the simulation model. USER49 can control the pitman arm rotation by feeding the rotation and its first and second derivative into the constraint element.

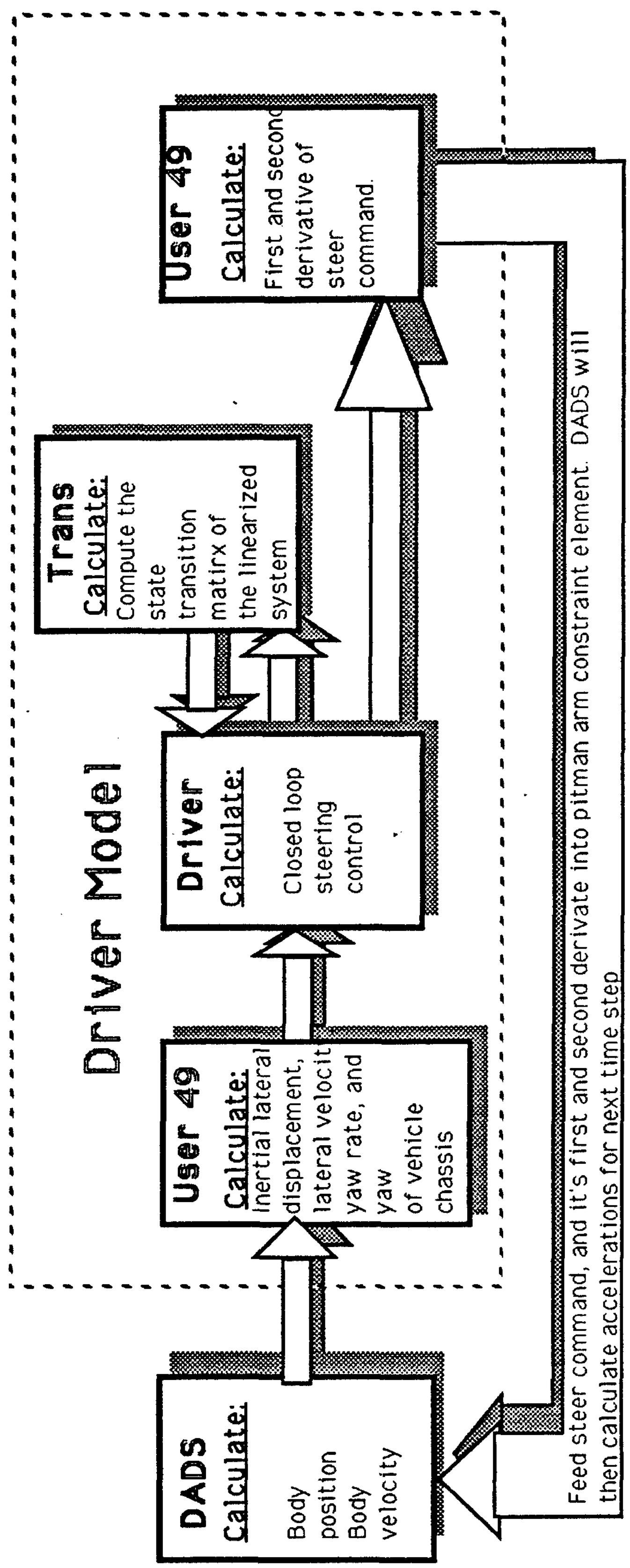

Figure 5.3.5-1 Driver model implementation

The driver model uses the subroutine DRIVGO to initialize it, and the subroutine DRIVER to calculate the closed loop steer command. After each successful integration step the DADS program has the position, orientation, and velocity of each body in the simulation. See Figure 5.3.5-1. USER49 calculates the global lateral position, velocity, yaw angle, yaw rate of the chassis and then calls subroutine DRIVER. If the current integration time is not at the start of a preview interval, then DRIVER will use equations 5.3.4-3 and 5.3.4-4 to calculate the control that will minimize the preview error performance measure defined in equation 5.3.4-1. If the current integration time step is at the start of the preview interval, DRIVER will also call subroutine TRANS to calculate and store away the state transition matrix of linearized vehicle model and its integral. The current vehicle tire cornering stiffnesses are provided to TRANS from the subroutine TIREF through a common block. DRIVER provides USER49 with the steer command for the current integration time. Two second order low pass filters estimate the steering commands first and the second derivative before they are provided to the DADS code.

5.4. Validation of Simulation Model

Validation tests for the simulation model were conducted in June and July 1988 at the Chrysler Chelsea Proving Grounds (CPG) in Chelsea Michigan, and at UMTRI in Ann Arbor, Michigan. The tests were designed to verify the quality of the output from the simulation, and to determine qualitatively how the vehicle handles in various types of maneuvers. Table 5.4-1 shows how the vehicle and trailer were instrumented to measure a system state variables.

Table 5.4-1 Truck/Trailer measurements.

State variable	Measurement
Vehicle lateral acceleration	Accelerometer near vehicle CG
Vehicle longitudinal acceleration	Accelerometer near vehicle CG
Vehicle yaw rate	Gyro orientated along vertical axis
Vehicle roll	Tilt angle of stabilized platform
Steer angle	Potentiometer on steering wheel
Front wheel steer front	Linear potentiometers between chassis and wheels
Vehicle speed	Fifth wheel and tachometer
Brake system pressure	Pressure transducer
Trailer lateral acceleration	Accelerometer near trailer CG
Articulation angle	String potentiometer between trailer and truck chassis
Trailer axle vertical position/roll angle	Two linear potentiometers placed +/- 18 inches from trailer center line between trailer axle and chassis

For safety reasons, the tests were conducted with the vehicle loaded to GVW of 7,500 lb rather than the normal 8,800 lb weight GVW. The difference in vehicle weight should pose no problem. The simulation model is still valid for a range of vehicle weights and CG locations. The trailer was loaded to a GVW of 3,160 lbs, with a center of gravity height of 41 inches. This configuration duplicates a generator payload, the trailer load most likely to roll over.

The vehicle and trailer was driven through a 100 by 12 ft lane change, 500 ft constant radius turn, and bump maneuvers. Vehicle braking during straight line and steady turn maneuvers was also conducted. Figures 5.4-1 and 5.4-2 show, respectively, the lane change course layout and the bump course cross section. The 100 by 12 lane change and 500 ft constant radius turn maneuvers are good measures of the on road stability of the vehicle, while the bump course provides an indication of the vehicle's off road stability.

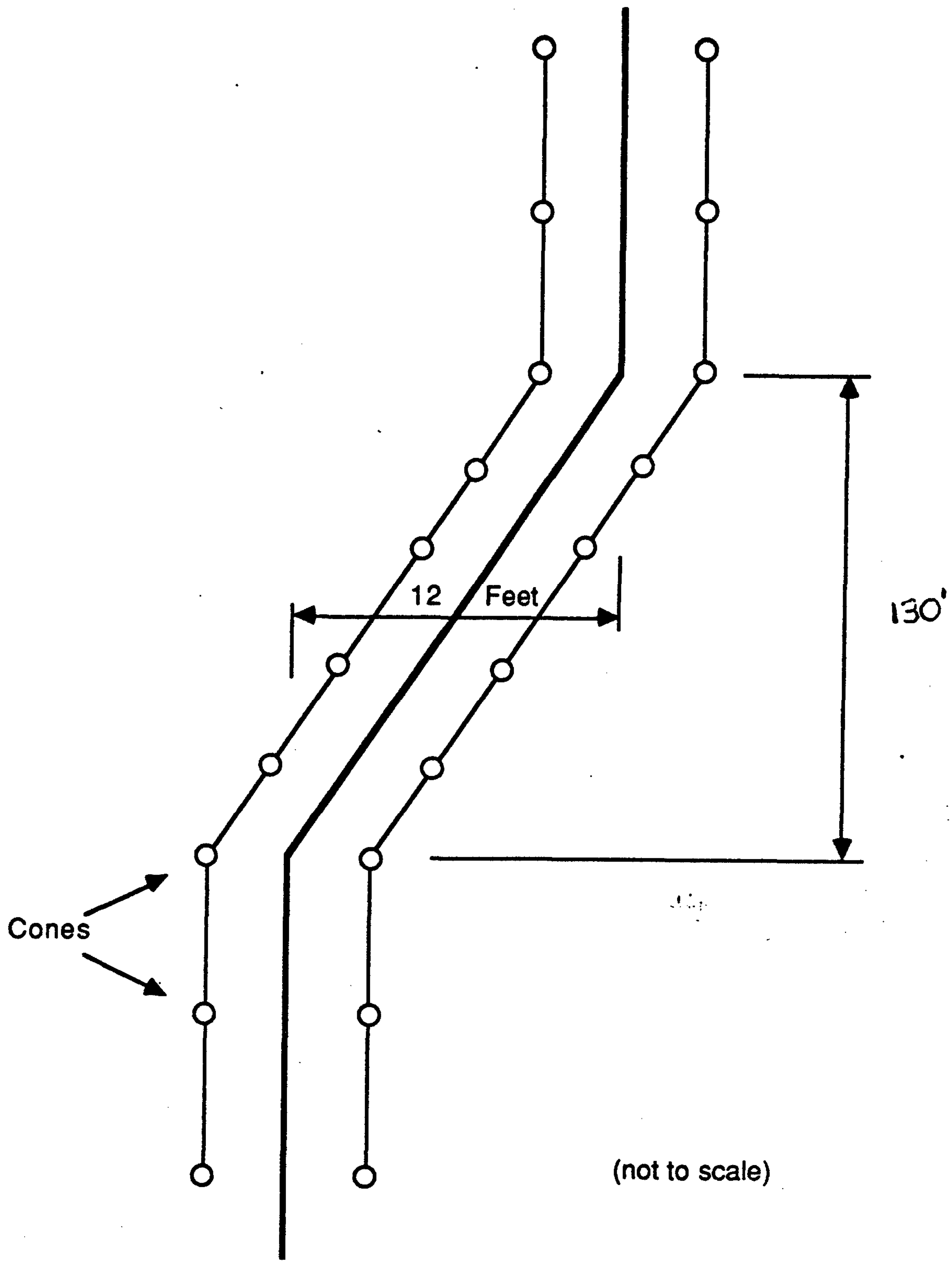

Figure 5.4-1 100 by 12 ft lane change course.

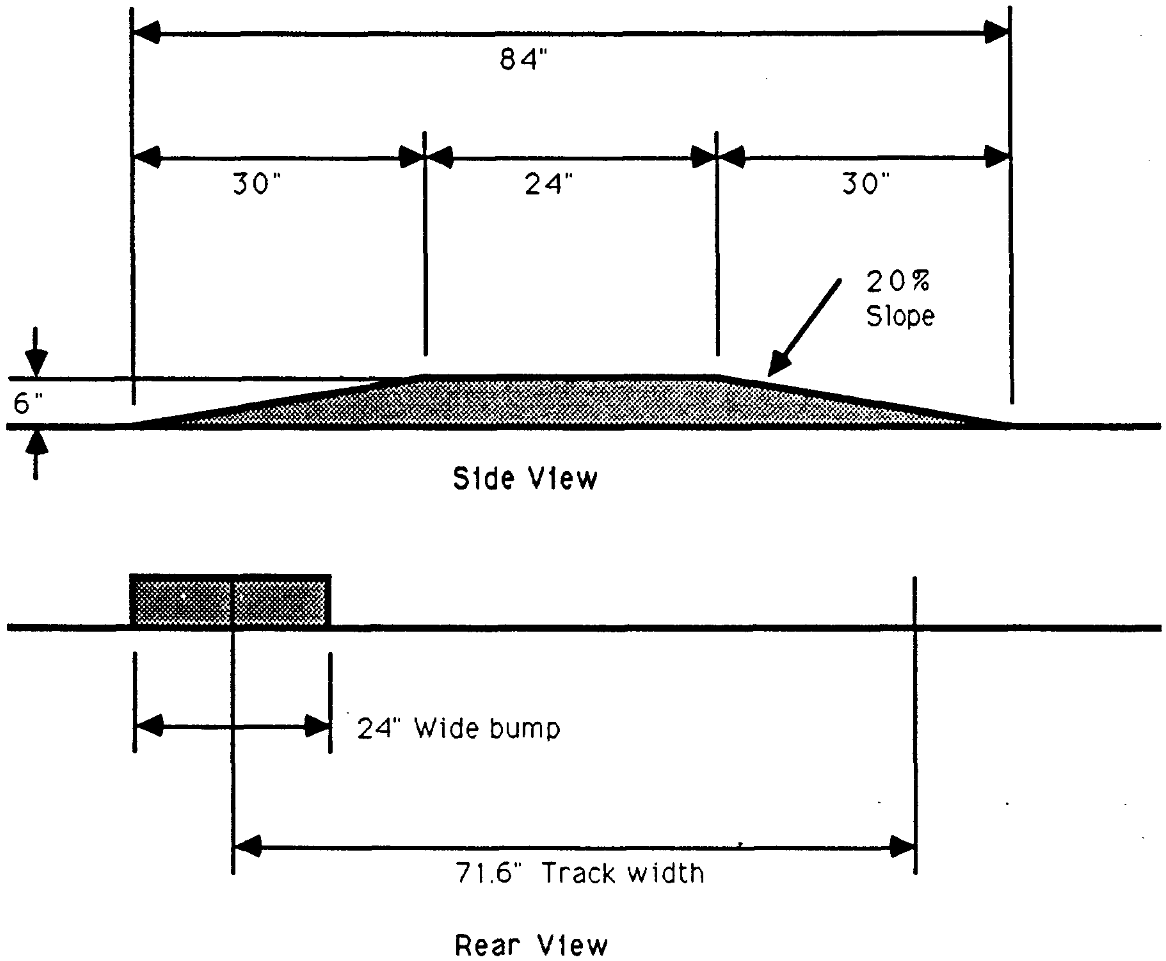

Figure 5.4-2 Bump course.

5.4.1. Validation of the M1037/M101 Simulation Model

Figures 5.4.1-1 through 5.4.1-8 show comparisons between the road tests and DADS simulation for a 45 mph 100 ft by 12 ft lane change maneuver. The yaw rate measurement in Figure 5.4.1-3, and the vehicle roll measurement in Figure 5.4.1-4 have a respective 2.5 deg/s and 0.5 deg bias. The measurement biases are the result of signal drift in the instrumentation, and do not exist in the actual system. In Figure 5.4.1-4 there is a large drop in the measurement at the end of the maneuver. The drop in the value of the signal is probably a result of bad spots in the stabilized platform potentiometer. The stabilized platform provides an inertial reference for vehicle roll and acceleration measurements.

The simulations were generated with preview and delay times for the driver model of 1.3 s and 0.1 s respectively.

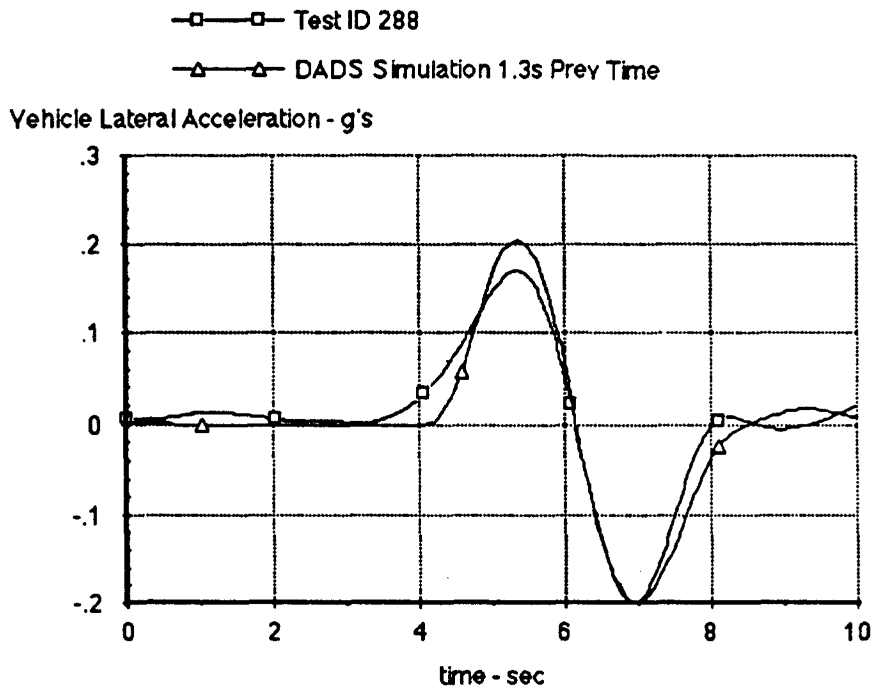

Figure 5.4.1-1 Lateral vehicle acceleration for a 45 mph 100 ft by 12 ft lane change.

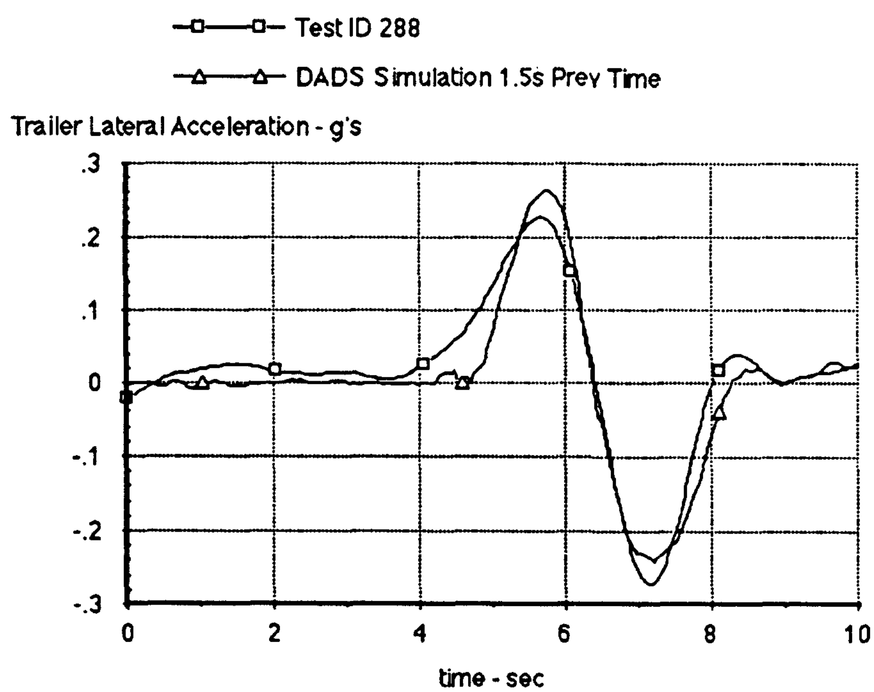

Figure 5.4.1-2 Lateral trailer acceleration for a 45 mph 100 ft by 12 ft lane change.

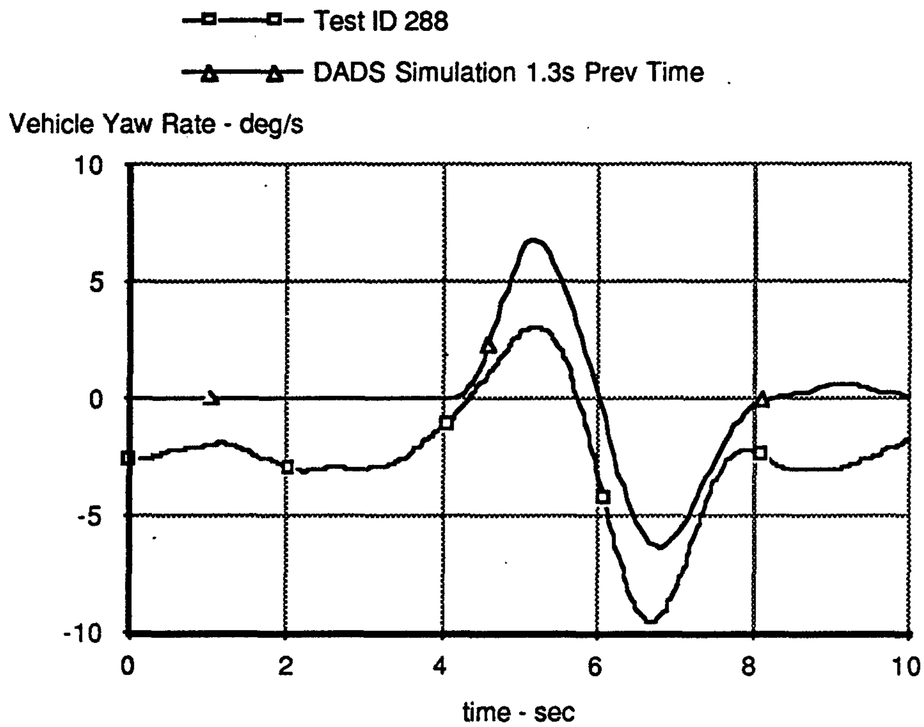

Figure 5.4.1-3 Vehicle yaw rate for a 45 mph 100 ft by 12 ft lane change.

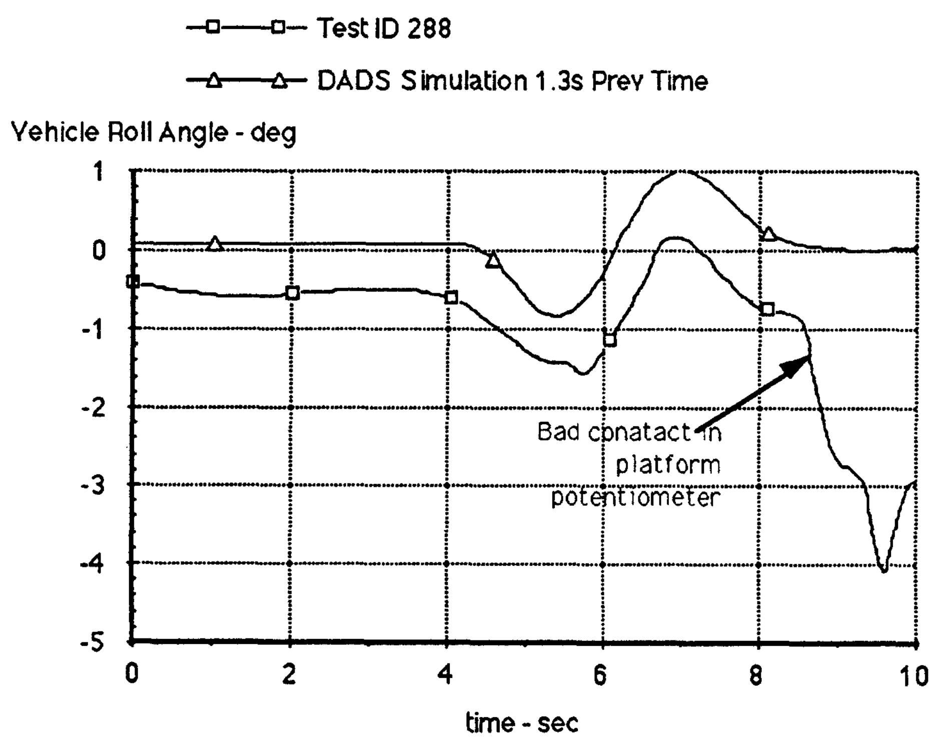

Figure 5.4.1-4 Vehicle roll for a 45 mph 100 ft by 12 ft lane change.

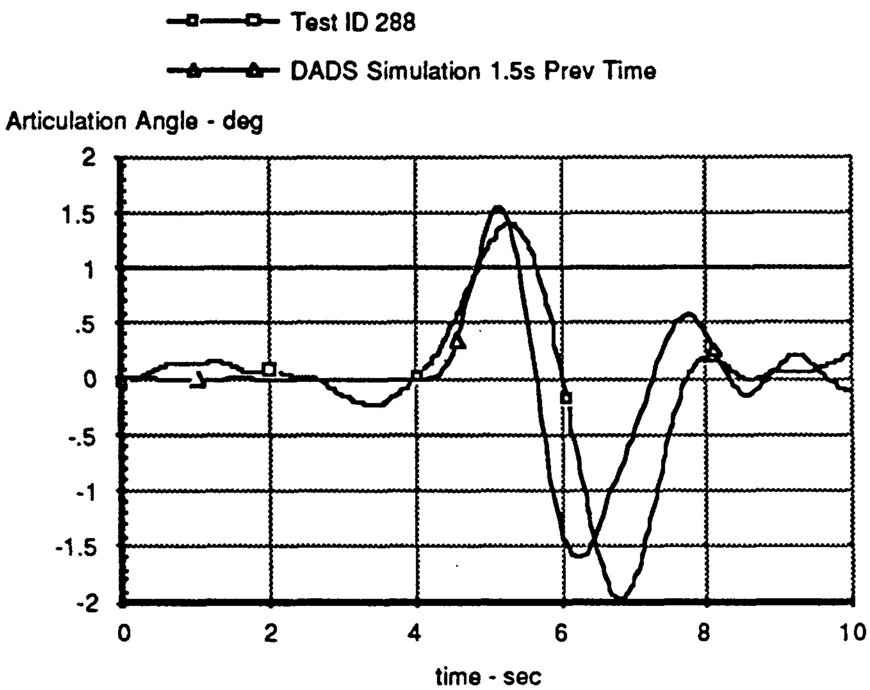

Figure 5.4.1-5 Articulation angle for a 45 mph 100 ft by 12 ft lane change.

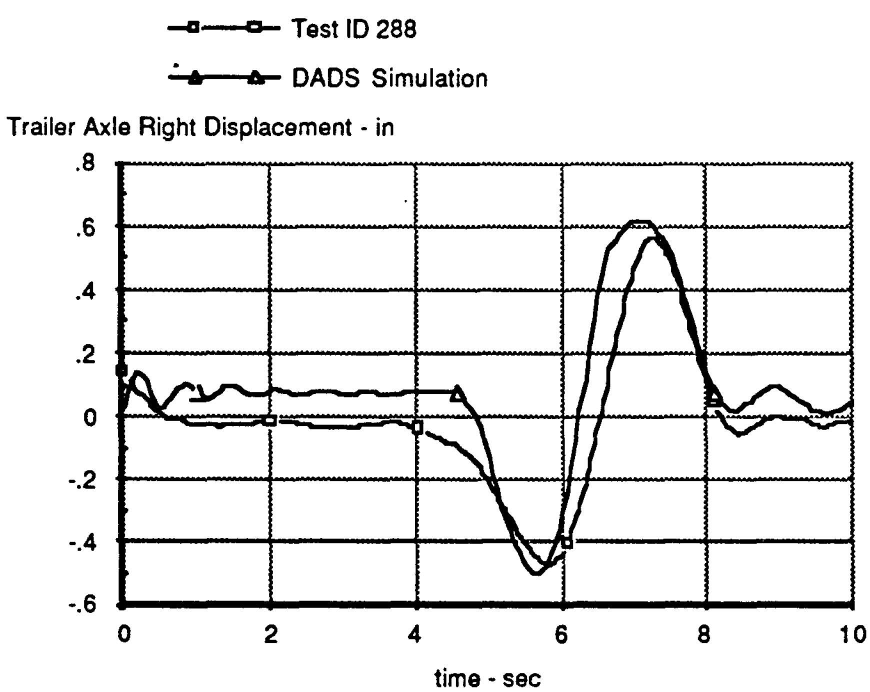

Figure 5.4.1-6 Trailer right axle displacement for a 45 mph 100 ft by 12 ft lane change.

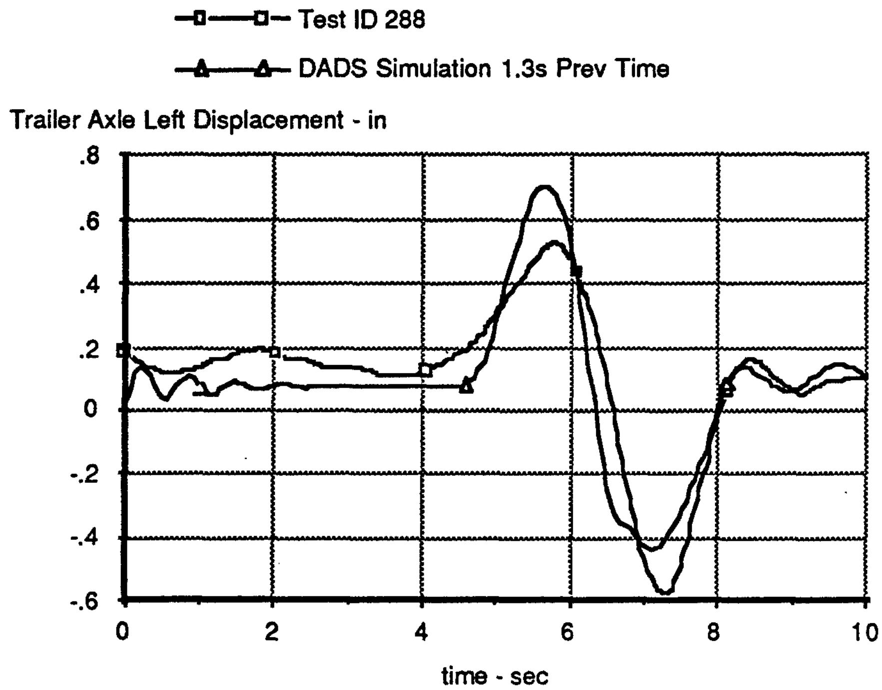

Figure 5.4.1-7 Trailer left axle displacement for a 45 mph 100 ft by 12 ft lane change.

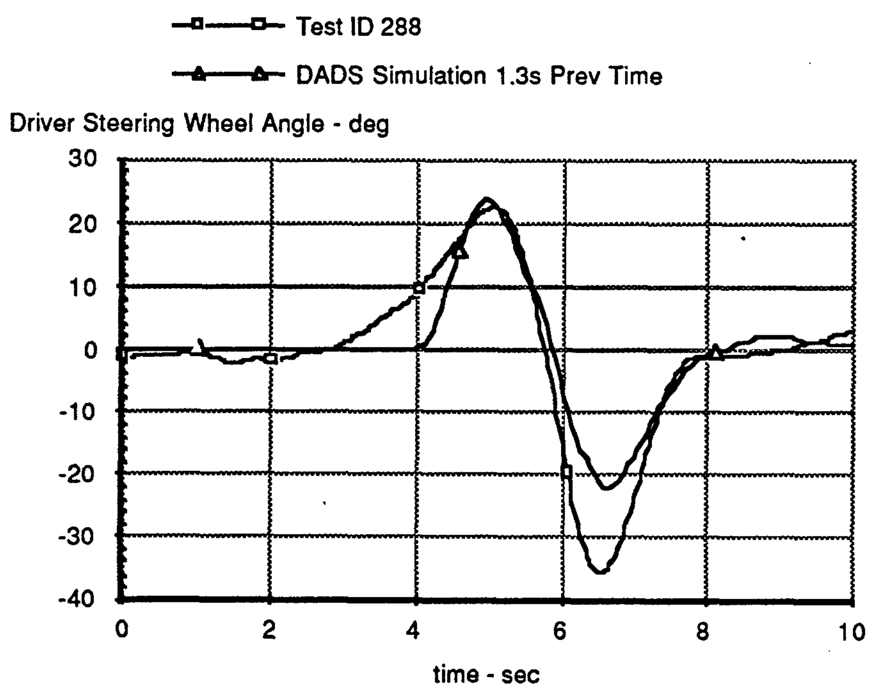

Figure 5.4.1-8 Steering wheel angle for a 45 mph 100 ft by 12 ft lane change.

Figures 5.4.1-9 through 5.4.1-15 show the simulated and measured response for a vehicle speed of 45 mph, 500 ft radius turn. With one exception, there was agreement between the simulation and test data. Figure 5.4.1-12 shows that the simulation underestimated the articulation angle. This could be due to a instrumentation calibration error for this particular test, or to some minor deficiency in the simulation model.

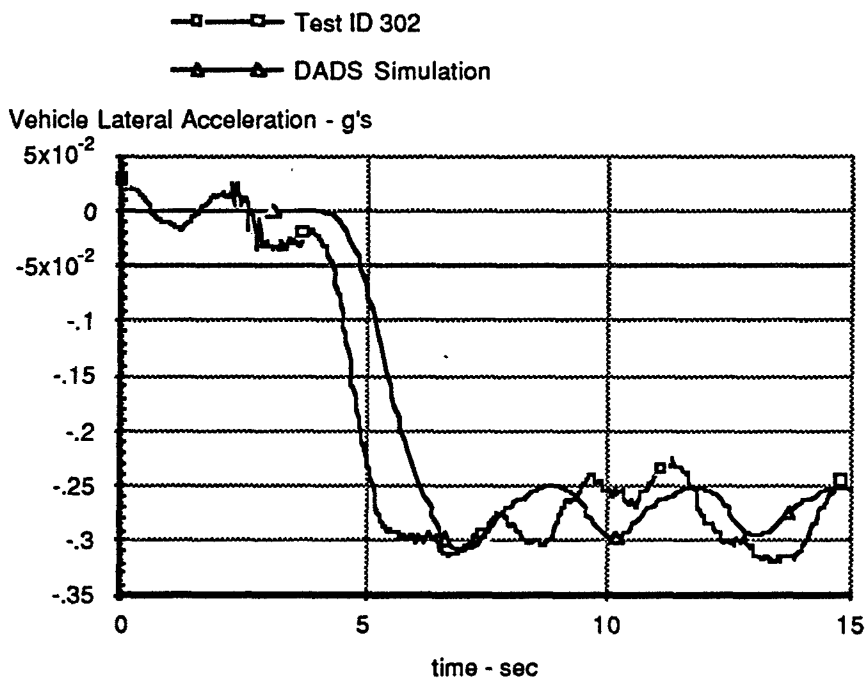

Figure 5.4.1-9 Lateral vehicle acceleration for a 45 mph 500 ft radius turn.

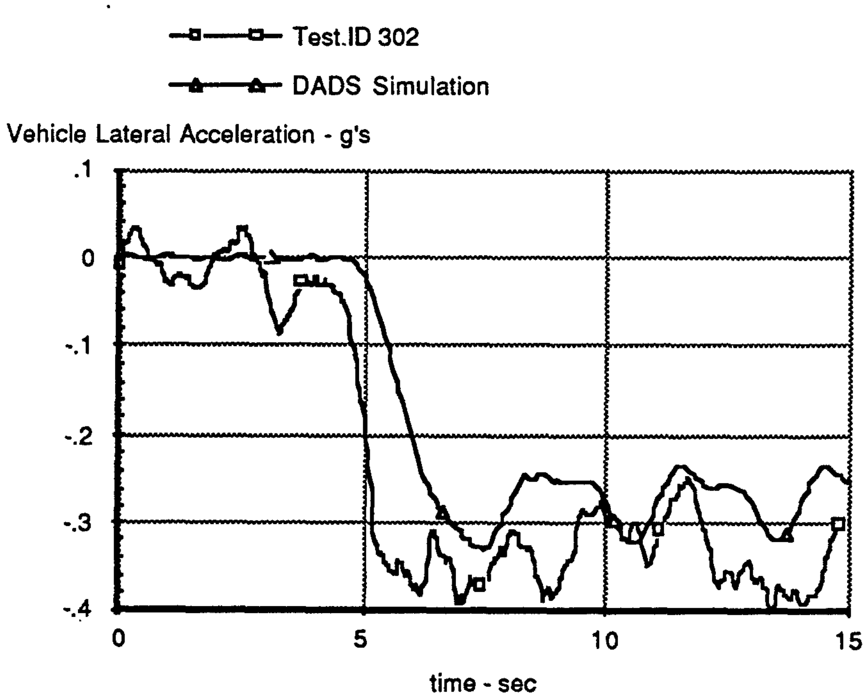

Figure 5.4.1-10 Lateral trailer acceleration for a 45 mph 500 ft radius turn.

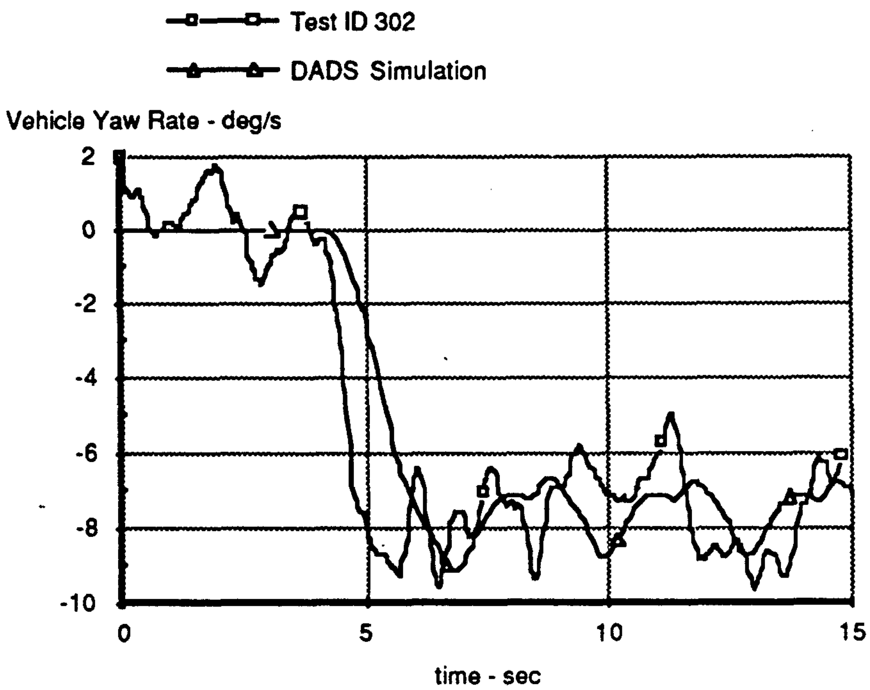

Figure 5.4.1-11 Vehicle yaw rate for a 45 mph 500 ft radius turn.

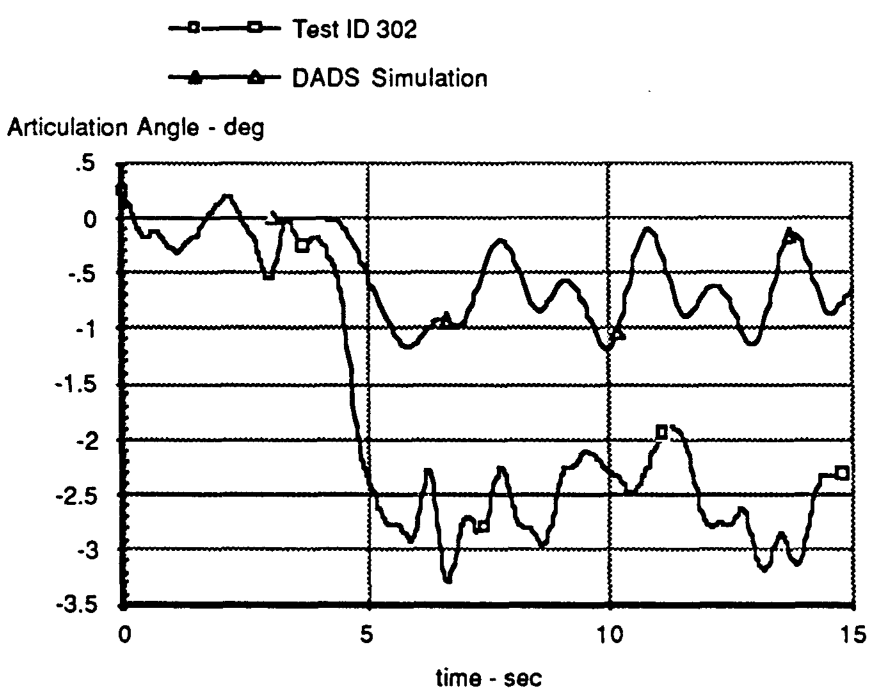

Figure 5.4.1-12 Articulation angle for a 45 mph 500 ft radius turn.

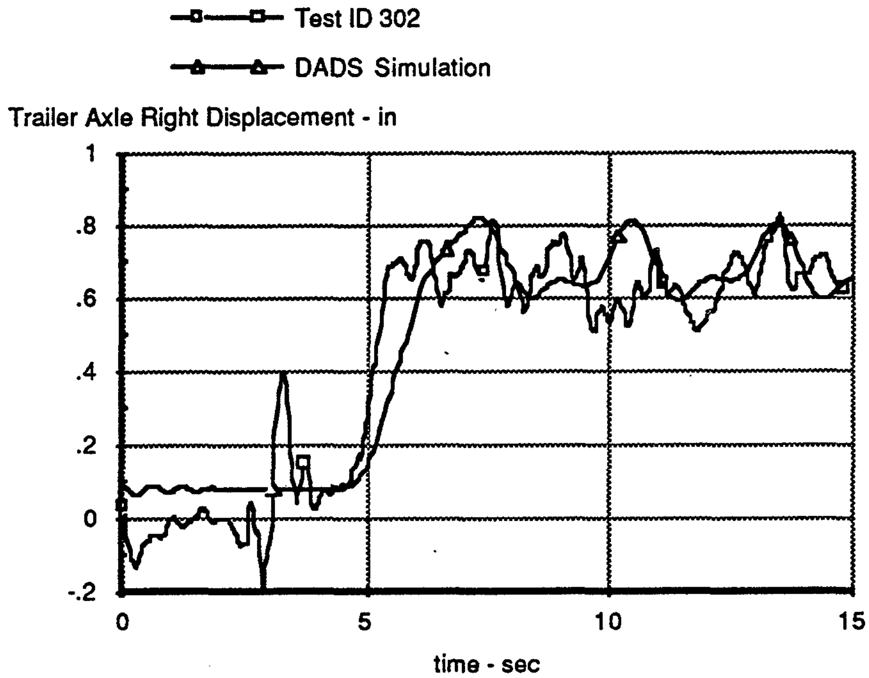

Figure 5.4.1-13 Trailer right axle displacement for a 500 ft radius turn.

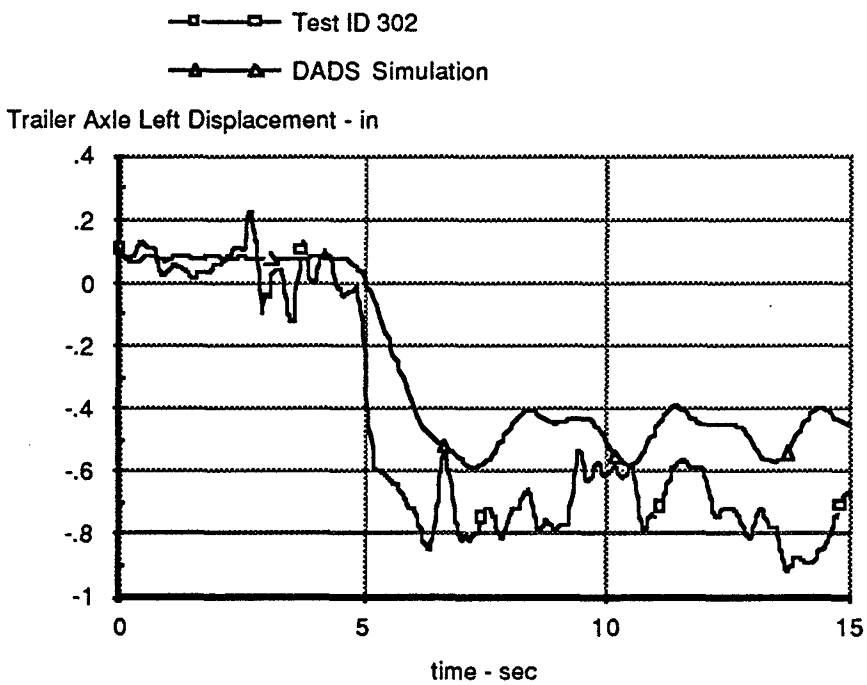

Figure 5.4.1-14 Trailer left axle displacement for a 45 mph 500 ft radius turn.

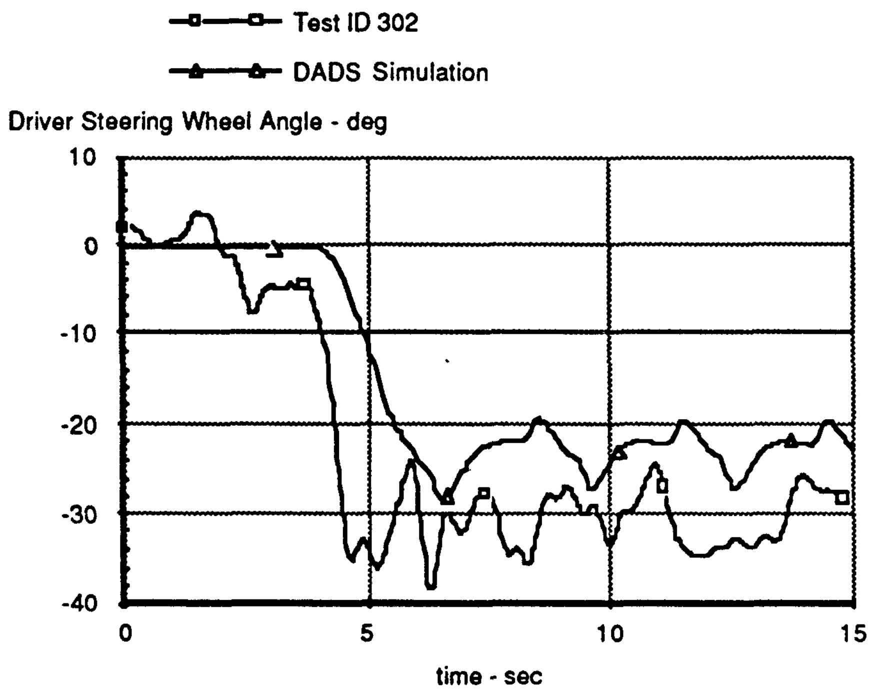

Figure 5.4.1-15 Steering wheel angle for a 45 mph 500 ft radius turn.

Figures 5.4.1-16 through 5.4.1-21 show vehicle response while traveling 10 mph over the bump course described in Figure 5.4-2. These figures indicate that there is reasonable agreement between simulation and road test vehicle responses with the exception of the articulation angle and left trailer axle displacement. The test data for the left trailer axle displacement did show a large negative spike at 7.2 s which the simulation did not fully reproduce. The cause of the spike has not yet been determined. One possible explanation is that the bump, which was not anchored to the ground, shifted while the trailer drove over it. The right trailer axle displacement measurement (the side where the vehicle traveled over the bump) did agree with the simulation results, however.

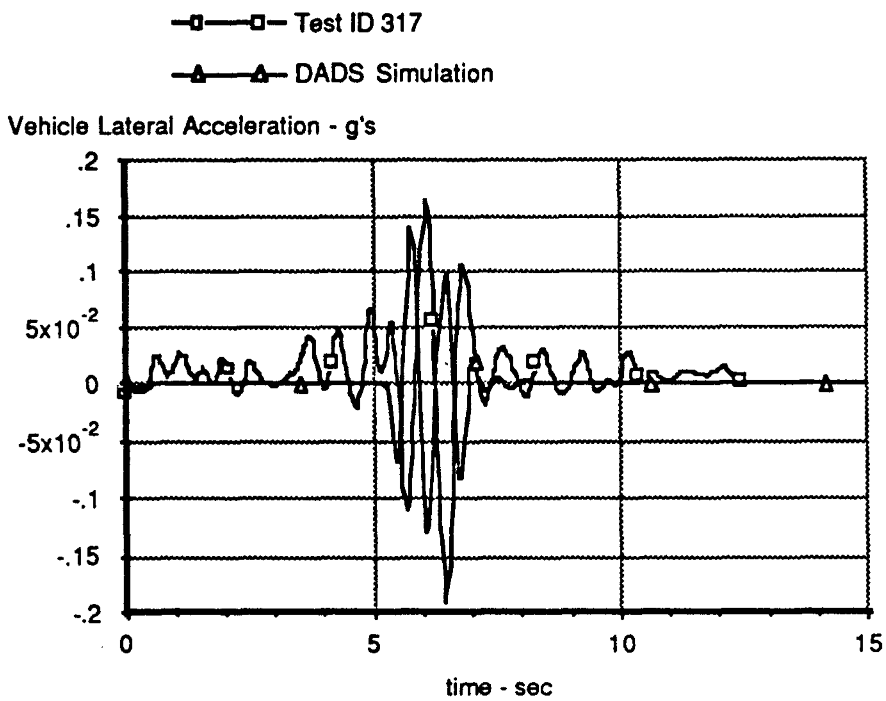

Figure 5.4.1-16 Lateral vehicle acceleration for a 6 inch bump course at 10 mph.

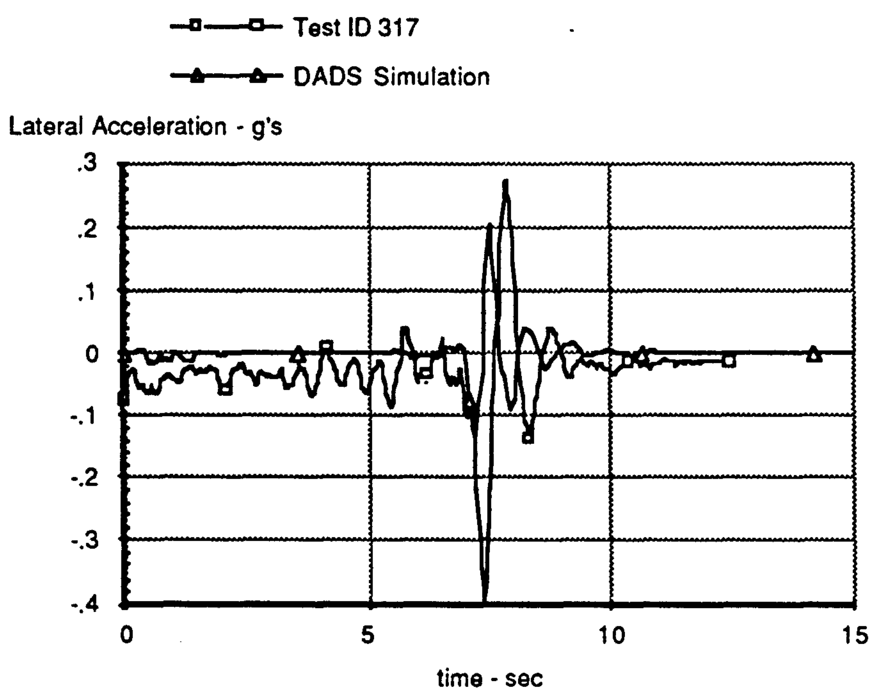

Figure 5.4.1-17 Lateral trailer acceleration for a 6 inch bump course at 10 mph.

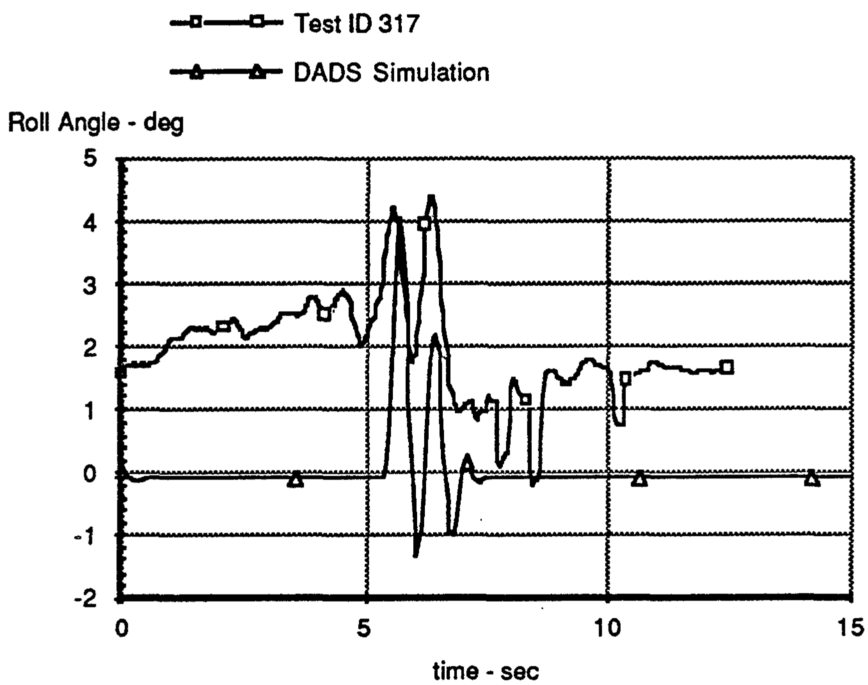

Figure 5.4.1-18 Vehicle roll for a 6 inch bump course at 10 mph.

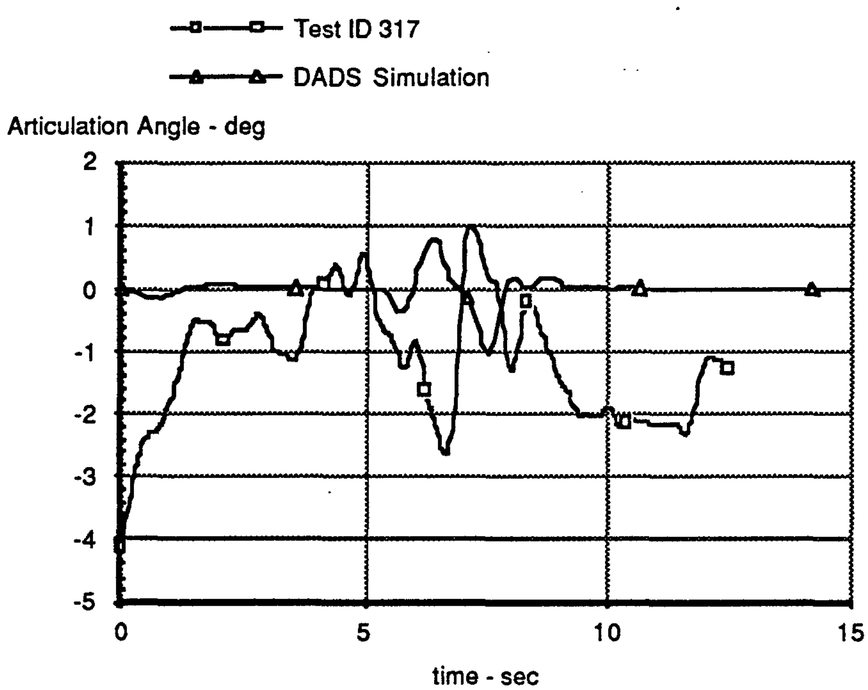

Figure 5.4.1-19 Articulation angle for a 6 inch bump course at 10 mph.

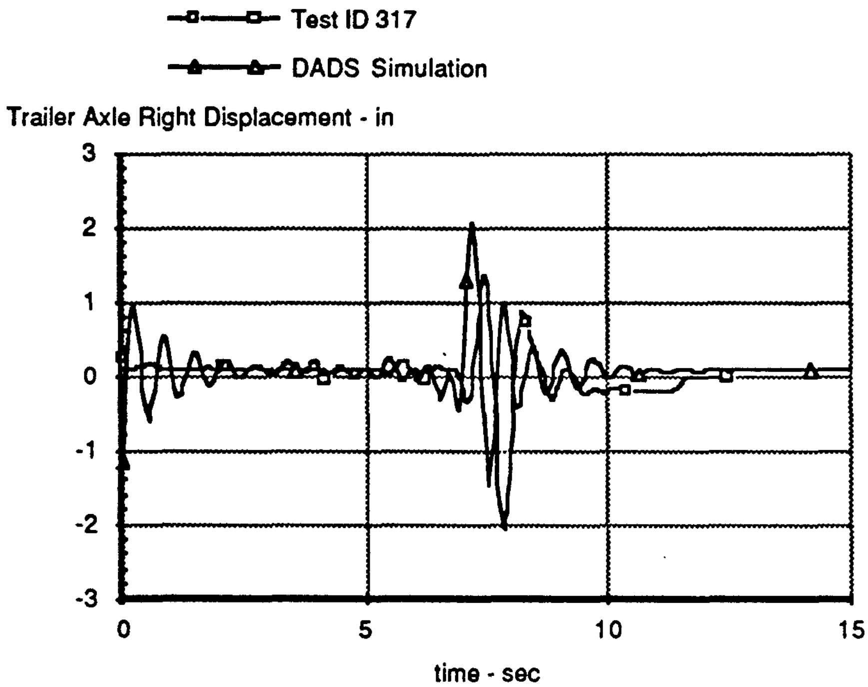

Figure 5.4.1-20 Trailer right axle displacement for a 6 inch bump course at 10 mph.

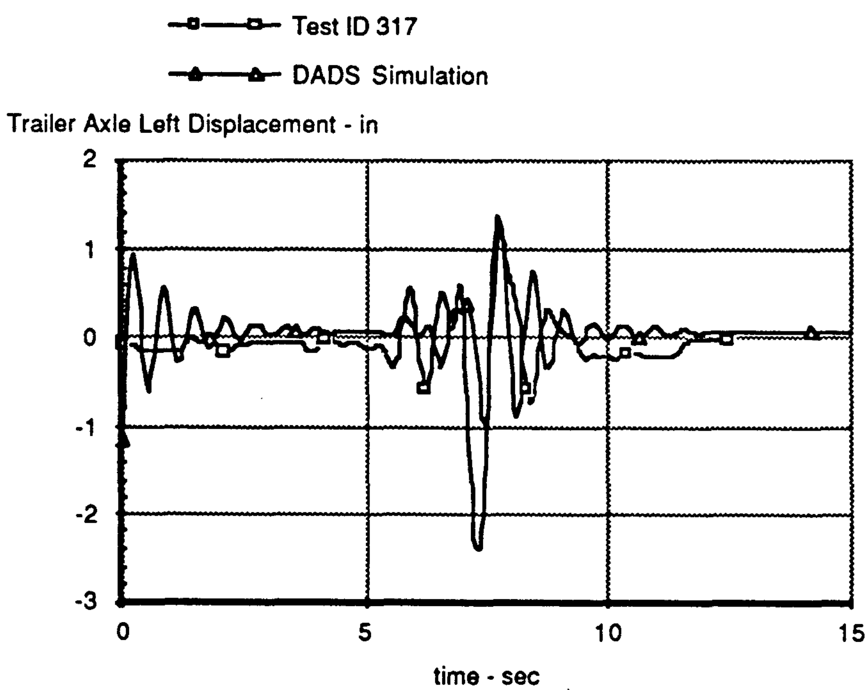

Figure 5.4.1-21 Trailer left axle displacement for a 6 inch bump course at 10 mph.

The figures in this section show that for the most part, the simulation model and actual tests agree. In most cases, both the magnitude and shape of the vehicle dynamic response were accurately reproduced. The results of the validation tests show that the simulation model should be adequate for predicting vehicle stability.

5.5. M1037 Simulation Results

The goal for this phase of the project was to determine the stability boundaries for the system during constant speed with on road and off road operation. To accomplish this, several maneuvers were chosen that taxed the stability of vehicle. The maneuvers included a lane change, a lane change on an inclined road, a constant radius turn, and a bump course. The first three maneuvers provide a measure of the vehicle on road performance, while the last maneuver generates a rough indication of the off-road stability.

5.5.1. Lane Change

In this part the vehicle was required to negotiate 100 ft by 12 ft lane change maneuver shown in Figure 5.4-1. Two combinations of front and rear tire inflations were examined. The first case was the nominal condition, 20 psi in the front tires and 30 psi in the rear tires. Simulations were conducted for vehicle speeds of 25 and 60 mph. Figures 5.5.1-1 through 5.5.1-6 show the vehicle response during a 60 mph lane change. Figure 5.5.1-1 shows the position of the vehicle CG in the global x-y plane. The vehicle tracks the prescribed trajectory with a maximum over shoot of about 3 ft, peak yaw rate of -8 deg/s, and peak lateral acceleration at the vehicle CG of about 0.28 g. Figure 5.5.1-5 shows a peak tire slip of about 3.3 deg. Table 5.5.1-1 shows peak values for all the vehicle speeds simulated.

Table 5.5.1-1 Peak values for the M1037 100 ft by 12 ft lane change simulations.

Speed	Tire Press	Lateral Acc.	Yaw rate	Roll	Tire Def	Tire Slip	Steer
mph	psi/psi	g's	deg/s	deg	inches	deg	deg
25	20/30	0.159	-8.2	1.24	2.06	1.46	2.79
25	30/30	0.159	-8.2	1.12	2.06	1.44	2.54
60	20/30	0.36	15.3	2.85	2.35	5.65	3.9
60	30/30	0.375	15.2	2.85	2.33	5.02	-4.3

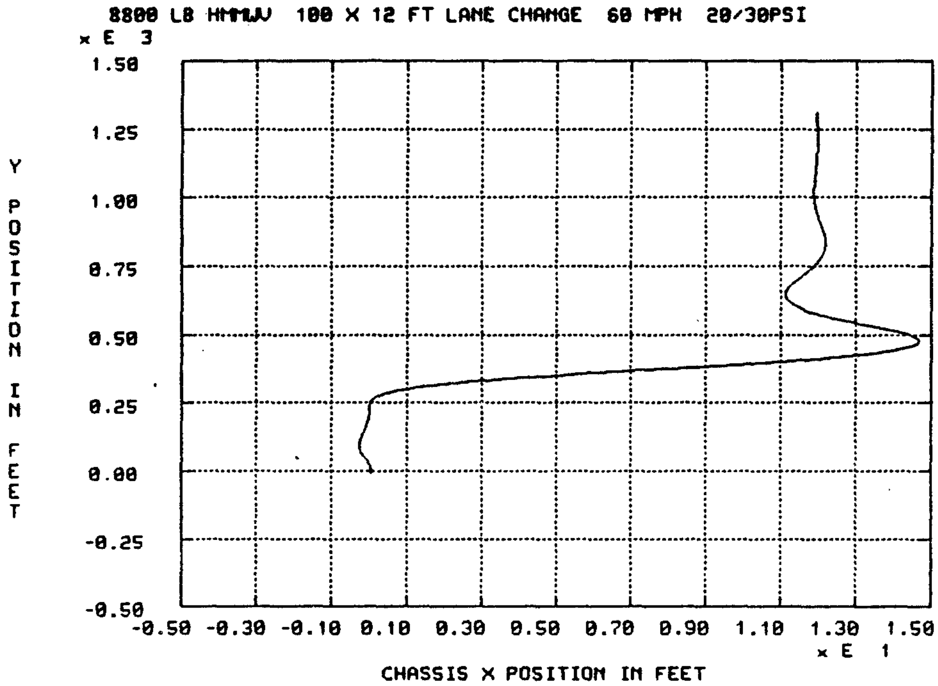

Figure 5.5.1-1 M1037 CG position for a 100 ft by 12 ft 60 mph lane change.

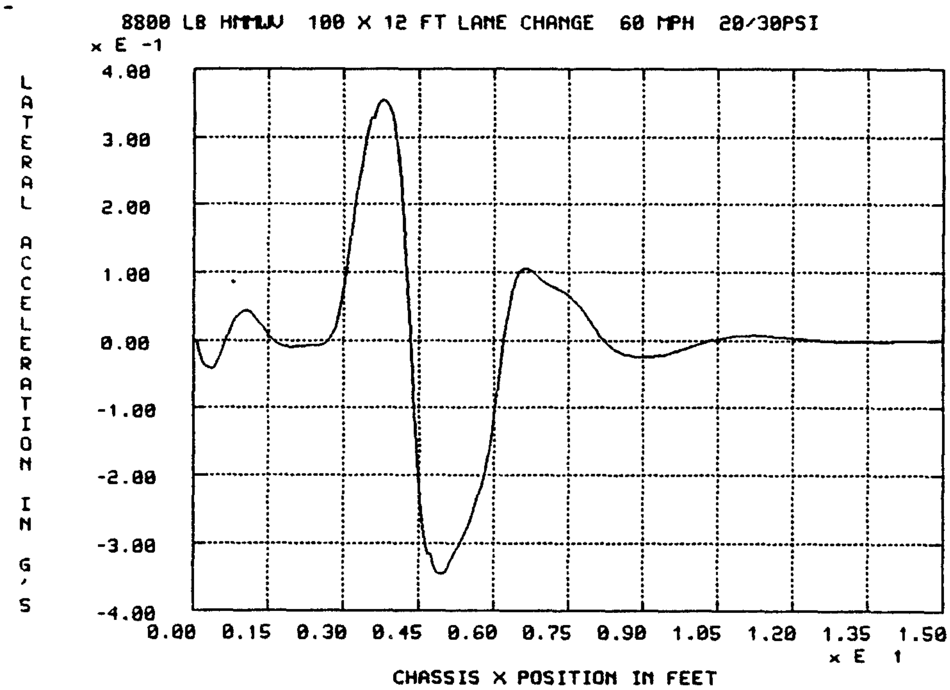

Figure 5.5.1-2 M1037 CG Lateral acceleration of vehicle CG for a 100 ft by 12 ft 60 mph lane change.

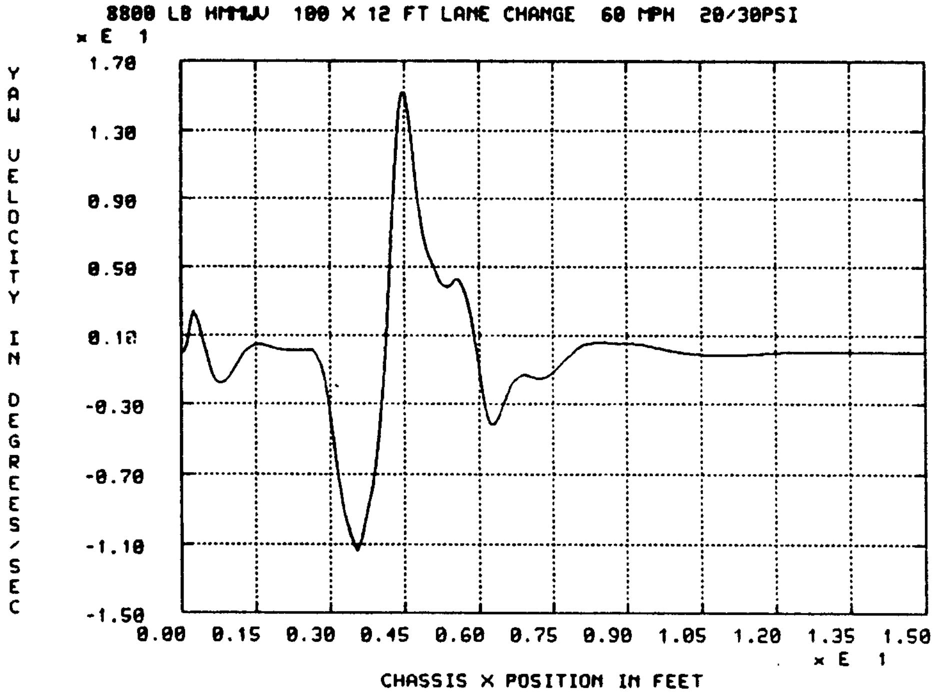

Figure 5.5.1-3 M1037 yaw rate for a 100 ft by 12 ft 60 mph lane change.

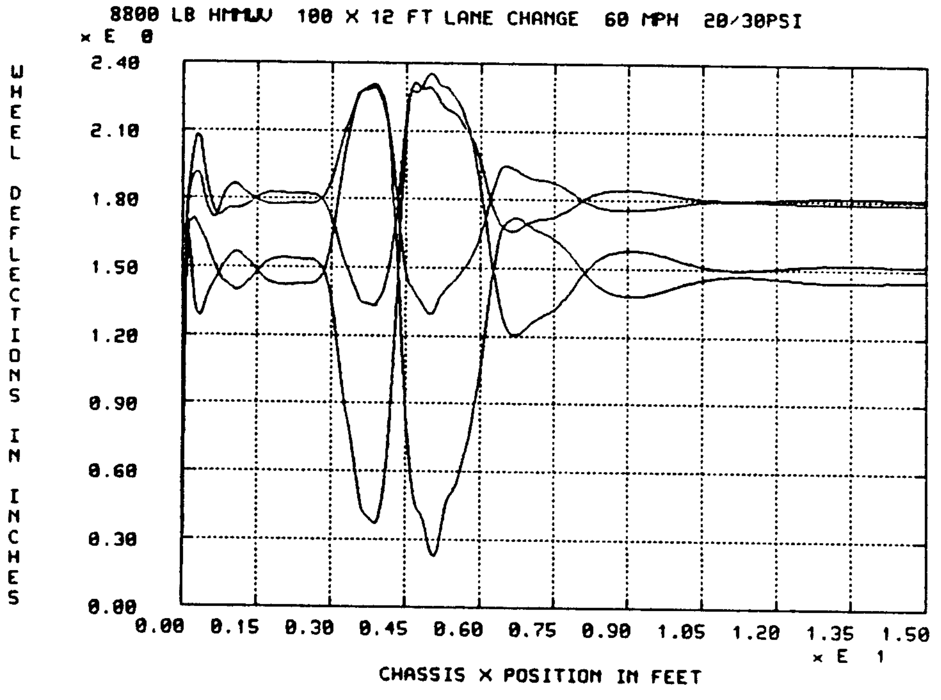

Figure 5.5.1-4 M1037 vertical tire deflections for a 100 ft by 12 ft 60 mph lane change.

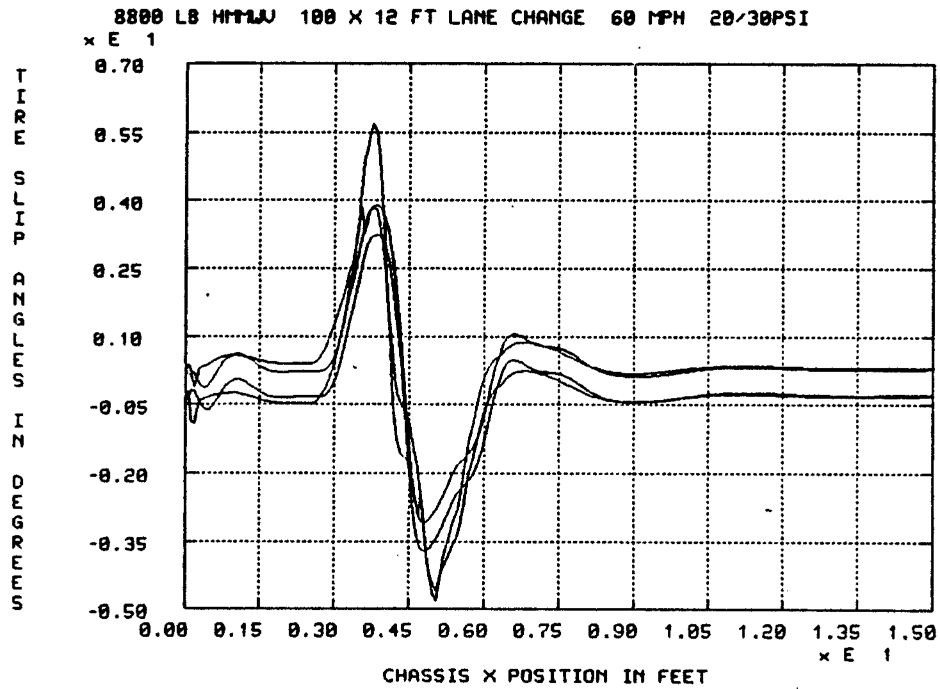

Figure 5.5.1-5 M1037 tire slip angles for a 100 ft by 12 ft 60 mph lane change.

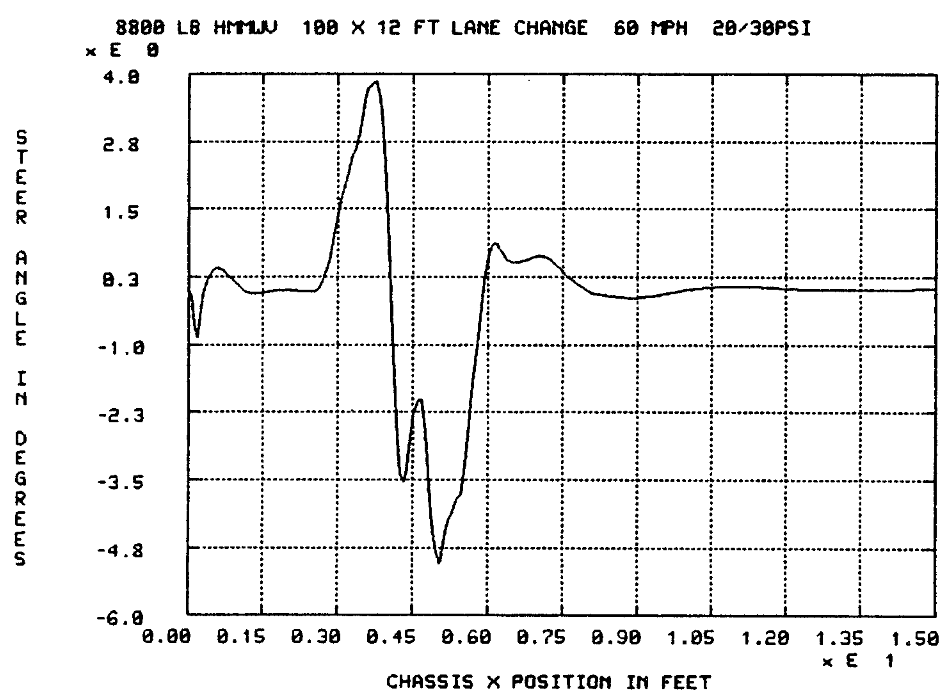

Figure 5.5.1-6 M1037 steer angle for a 100 ft by 12 ft 60 mph lane change.

5.5.2. Steady Turn

In this part of the study, the vehicle is required to maintain a constant speed through a 500 ft radius turn. As with section 5.5.1, both 20/30 psi and 30/30 psi front/rear inflation pressure combinations were simulated. Figures 5.5.2-1 through 5.5.2-6 show selected 50 mph simulation results for the 20/30 psi case. The simulation results in Table 5.5.2-1 showed that raising the inflation pressure of the front tires produced slightly lower peak responses. The simulation shows that the vehicle can maintain vehicle speeds of 50 mph (lateral accelerations of 0.3 g's) without yaw or roll instability, but was not stable at 55 mph (lateral accelerations of 0.405 g's).

Table 5.5.2-1 Peak values for the M1037 500 ft radius steady turn simulations.

Speed	Tire Press	Lateral Acc.	Yaw rate	Steer	Tire Def	Tire Slip
mph	psi/psi	g's	deg/s	deg	inches	deg
25	20/30	0.093	-4.7	1.44	2.00	0.96
25	30/30	0.092	-4.55	1.42	2.03	0.90
50	20/30	0.425	-13.7	8.5	2.56	10.3
50	30/30	0.396	-11.0	5.2	2.30	6.5
55	20/30	(unstable)				

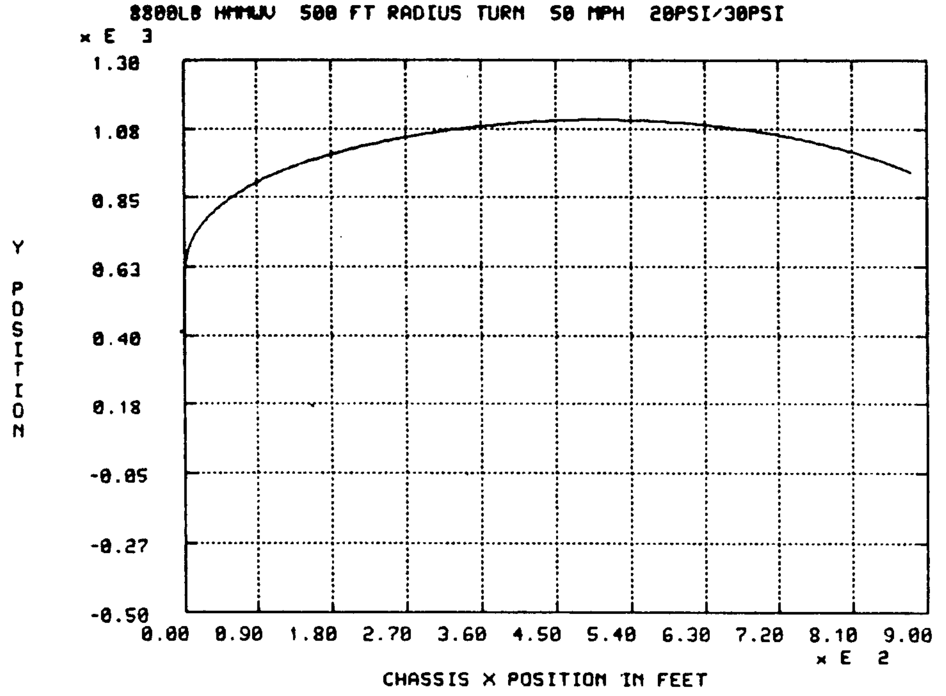

Figure 5.5.2-1 M1037 CG position, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

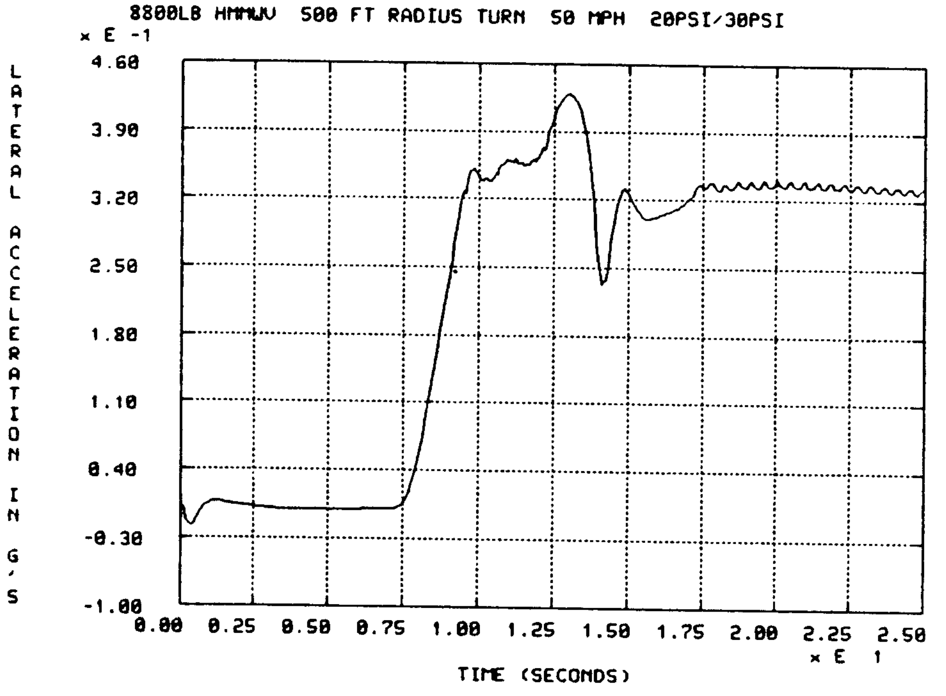

Figure 5.5.2-2 M1037 CG lateral acceleration, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

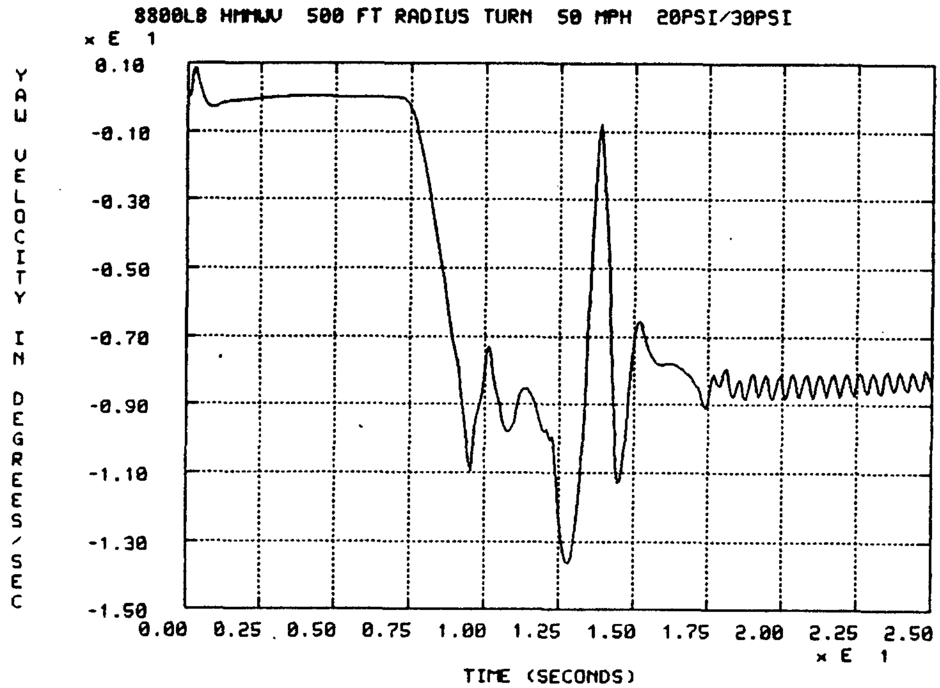

Figure 5.5.2-3 M1037 yaw rate, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

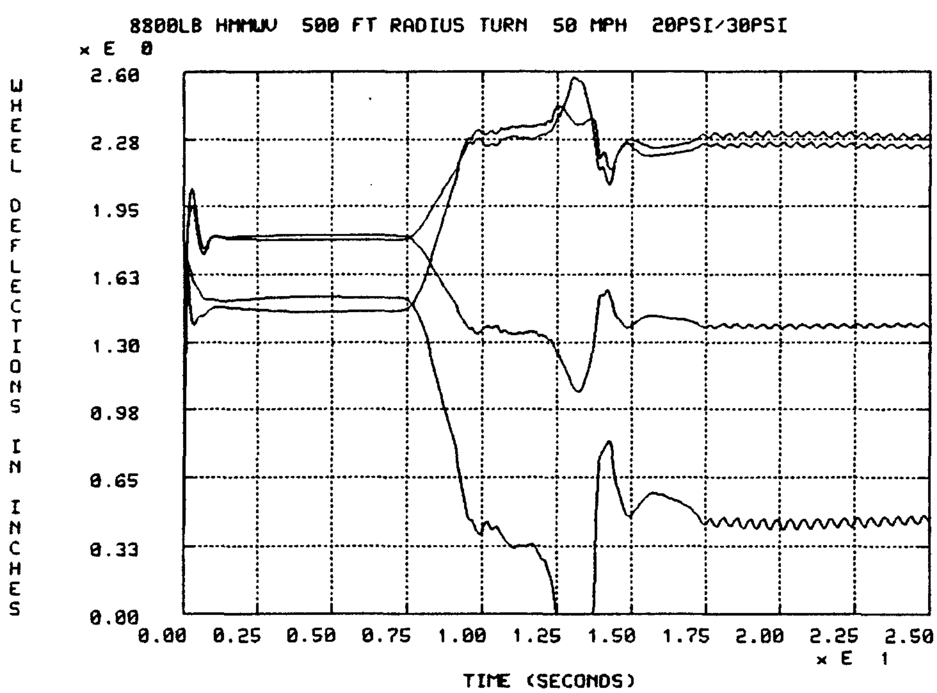

Figure 5.5.2-4 M1037 vertical tire deflections, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

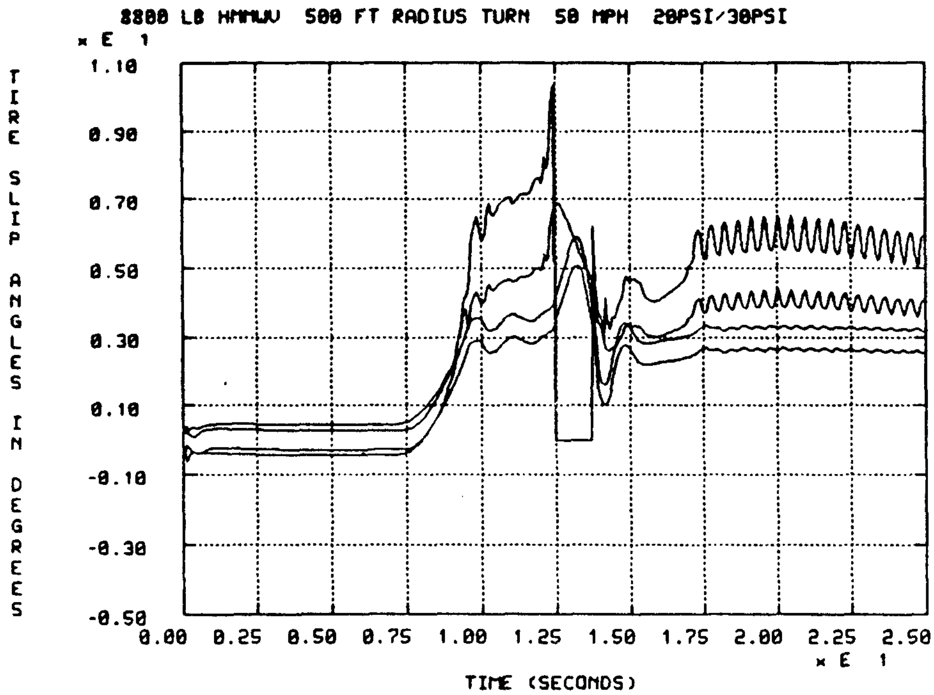

Figure 5.5.2-5 M1037 tire slip angles, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

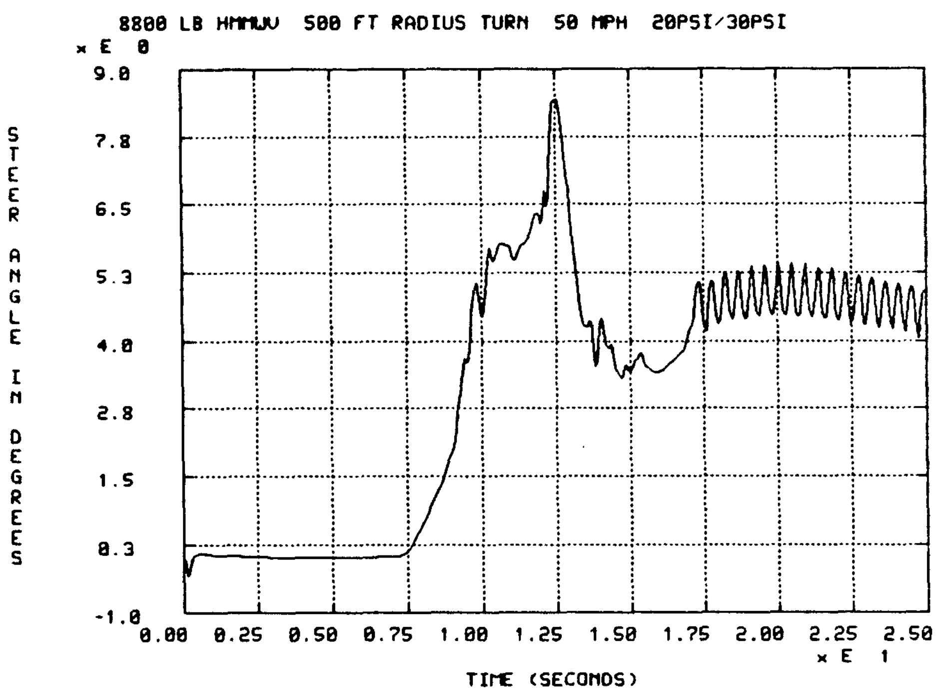

Figure 5.5.2-6 M1037 steer angle, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

5.5.3. Bump Course

To evaluate roll stability, the vehicle was driven over the 6 inch high bump described in section 5.4. The 20/30 psi pressure front/rear tire inflation pressure combination was simulated in this case. Figures 5.5.3-1 through 5.5.3-8 show the vehicle's response while traveling over the bump at 15 mph. Table 5.5.3-1 shows the corresponding peak values for the responses.

Table 5.5.3-1 Peak values for the M1037 bump course simulations.

Speed	Tire Press	Lateral Acc.	Vertical Acc.	Roll	Tire Def	Suspen Roll
mph	psi/psi	g's	g's	deg	inches	deg
10	20/30	-0.26	-0.37	-4.2	3.6	1.11
15	20/30	0.214	-0.42	-3.8	3.55	1.23
20	20/30	0.192	-0.44	-3.4	3.75	1.21
25	20/30	0.161	-0.44	-3.0	3.90	1.46
30	20/30	-0.159	0.43	-2.85	3.35	1.47
35	20/30	0.122	-0.39	-2.52	4.6	1.44
40	20/30	-0.184	0.465	-2.25	3.7	1.61
45	20/30	0.145	0.495	-2.18	5.1	1.16
50	20/30	0.134	-0.42	-1.99	5.4	1.18
55	20/30	0.144	0.98	-1.97	3.7	1.48

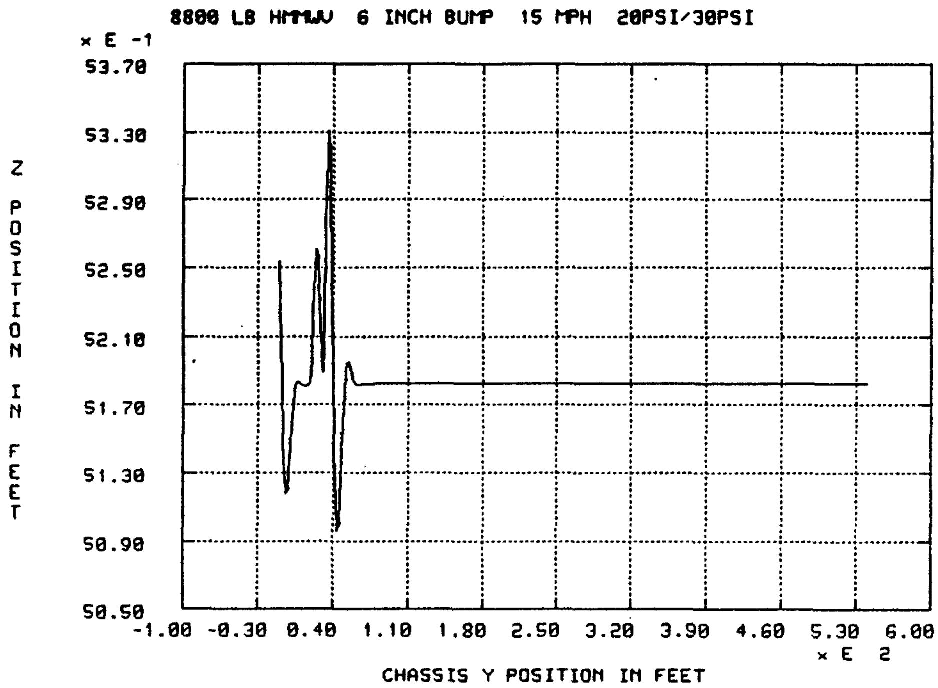

Figure 5.5.3-1 M1037 chassis CG vertical position, 6 inch bump course, 15 mph.

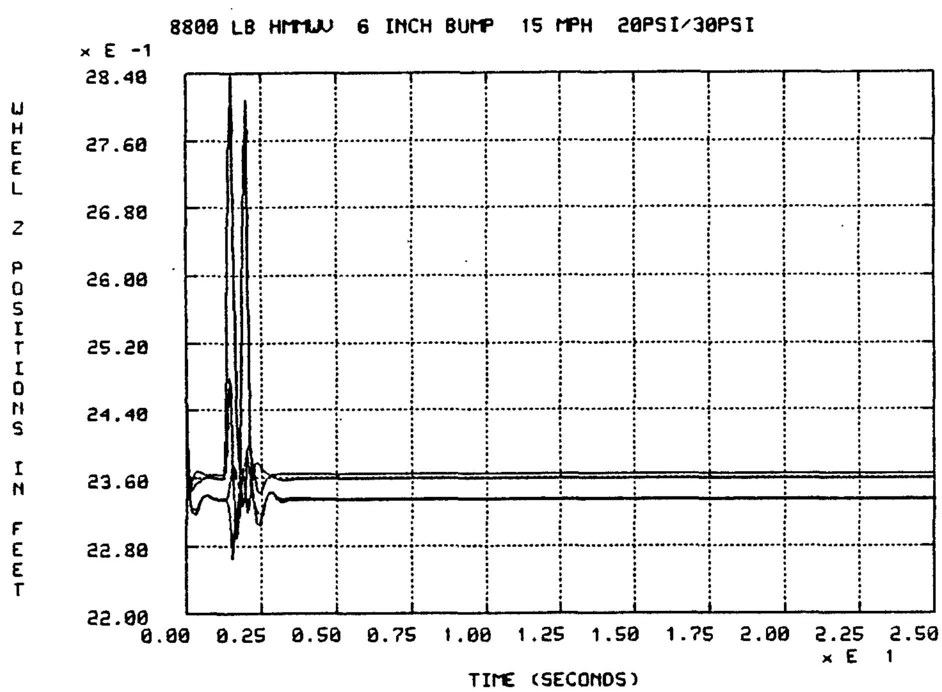

Figure 5.5.3-2 M1037 tire vertical position, 6 inch bump course, 15 mph.

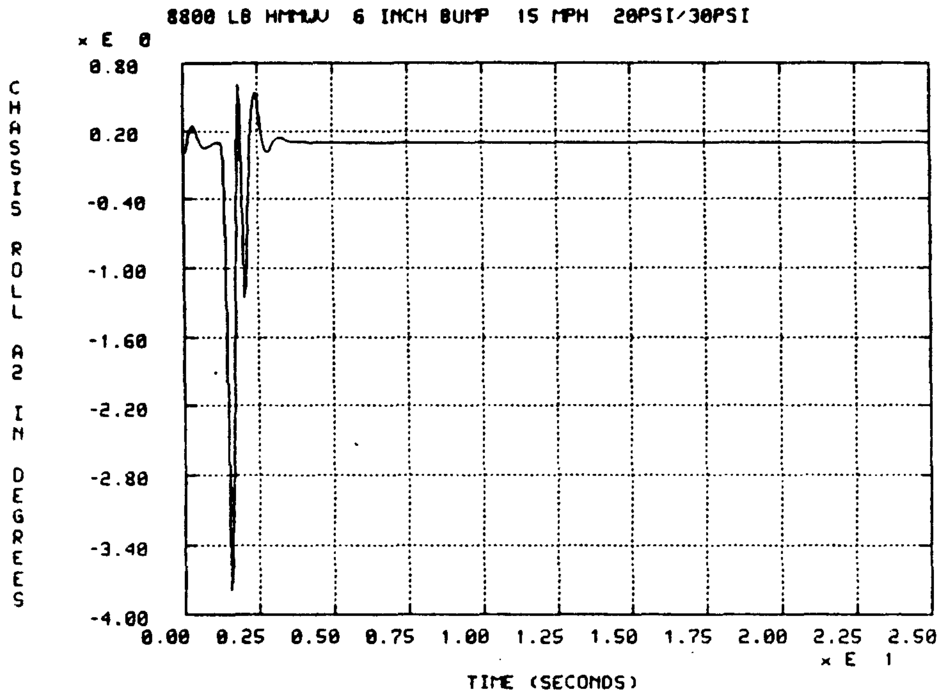

Figure 5.5.3-3 M1037 chassis roll angle, 6 inch bump course, 15 mph.

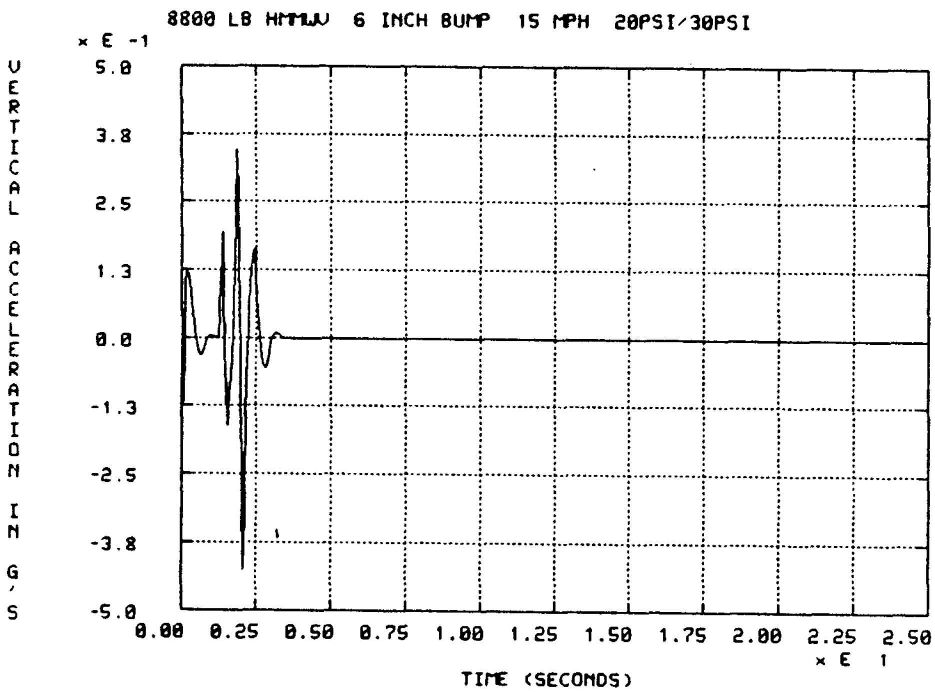

Figure 5.5.3-4 M1037 chassis vertical acceleration, 6 inch bump course, 15 mph.

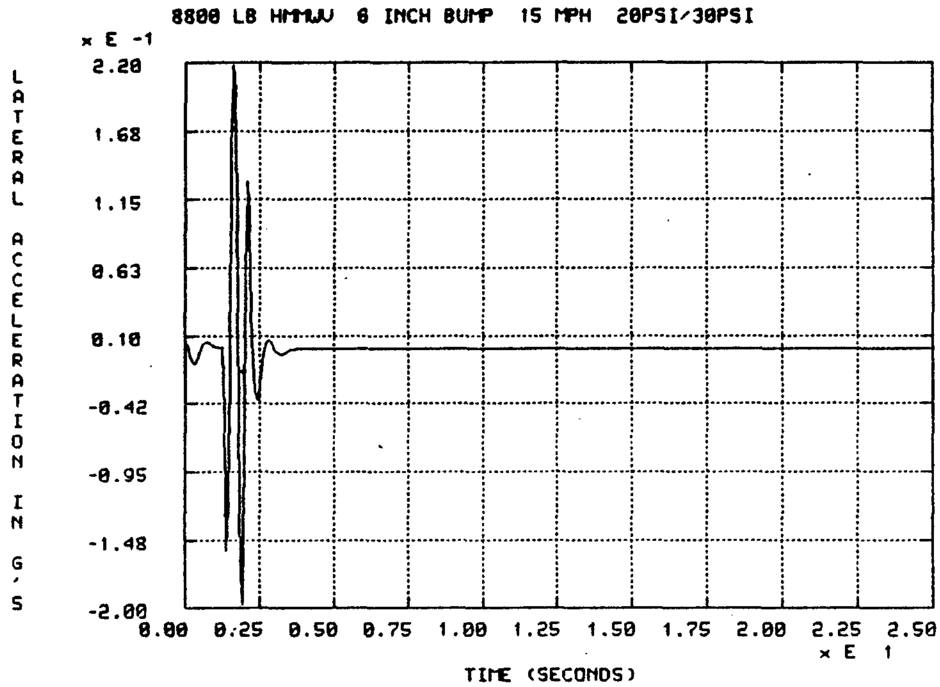

Figure 5.5.3-5 M1037 chassis CG lateral acceleration, 6 inch bump course, 15 mph.

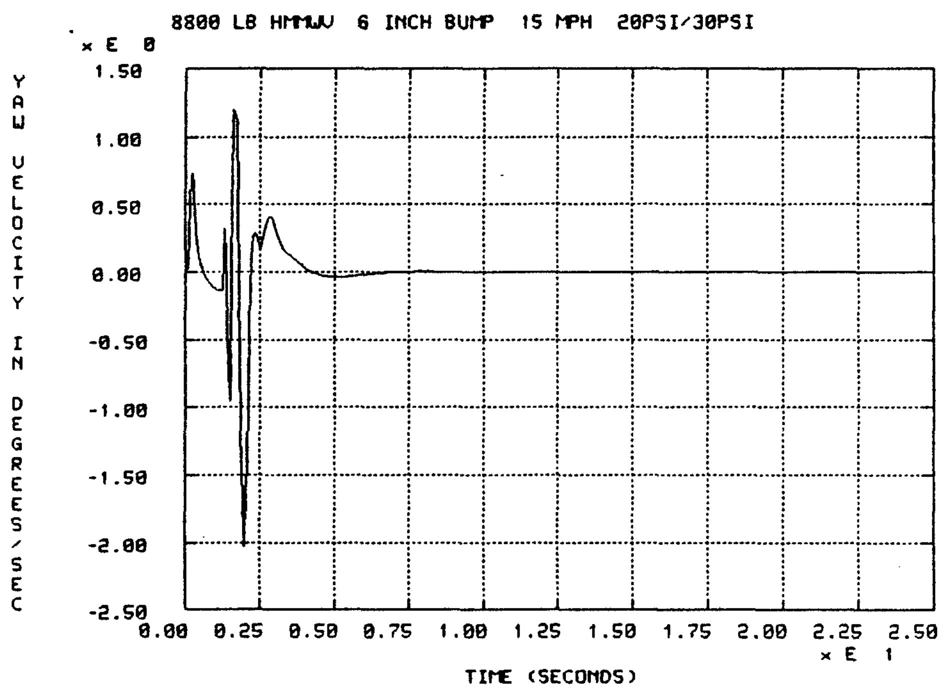

Figure 5.5.3-6 M1037 chassis yaw rate, 6 inch bump course, 15 mph.

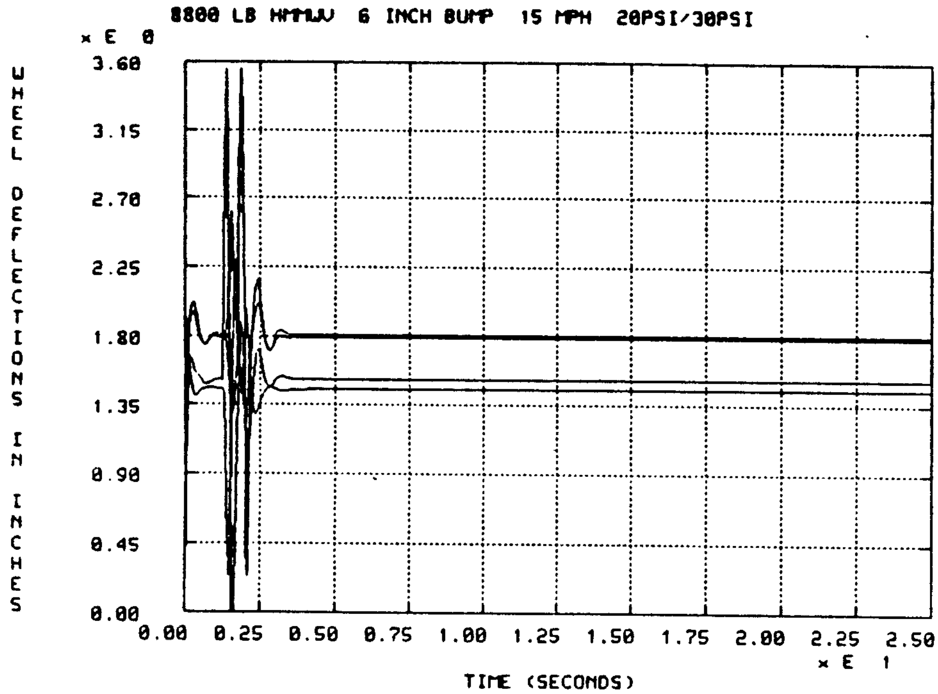

Figure 5.5.3-8 M1037 wheel deflection, 6 inch bump course, 15 mph.

5.5.4. Maneuvering on an Inclined Slope

100 ft by 12 ft lane change vehicle simulations were generated for both a 15% and 29% down hill grade, and 15% side slope. Steady turning of the vehicle in a 500 ft radius turn on a 15% inclined slope was also simulated. Table 5.5.4-1 shows the peak values generated by the simulations. The vehicle became unstable during the 45 mph 15% side slope lane change maneuver. The vehicle was also marginally stable during the 60 mph 29% downhill lane change maneuver.

Table 5.5.4-1 Peak values for the M1037 inclined slope simulations.

Speed	Course	Lateral Acc.	Yaw rate	Steer	Tire Def	Tire Slip
mph		g's	deg/s	deg	inches	deg
25	15% Slope turn	0.093	-4.7	1.44	2.00	0.96
50	15% Slope turn	0.092	-4.55	1.42	2.03	0.90
25	15% DH LC	0.425	-13.7	8.5	2.56	10.3
60	15% DH LC	0.396	-11.0	5.2	2.30	6.5
25	29% DH LC	0.153	-8.2	2.9	2.08	2.18
60	29% DH LC	-0.32	10.7	-6.3	2.46	7.6
25	15% SS LC	0.159	8.7	-4.06	2.26	-3.56
35	15% SS LC	0.21	8.65	-6.3	2.35	-7.4
40	15% SS LC	0.257	-11.1	-8.4	2.53	-9.5

5.6. M1037/M101 Simulation Results

In this part, the stability of the M1037 truck and M101 trailer was examined for the maneuvers described in section 5.5.

5.6.1. Lane Change

In this part, the M1037/M101 is required to negotiate a 100 ft by 12 ft lane change maneuver. See Figure 5.4-1. Table 5.6.1-1 shows peak values from the simulation results. The vehicle had no difficulty negotiating the maneuver for speeds of up to 60 mph. Figures 5.6.1-1 through 5.6.1-8 show the simulation output for the 60 mph maneuver.

Table 5.6.1-1 Peak values for the M1037/M101 100 ft by 12 ft lane change simulations.

Speed	Truck/Trailer Lateral Acc.	Truck/Trailer Yaw rate	Articulation angle	Steer	Tire Def	Tire Slip
mph	g's	deg/s	deg	deg	inches	deg
25	-0.116/ 0.138	6.2/6.9	-2.02	-1.85	2.56/2.36	2.56
60	-0.270/-0.495	10.3/21.5	-4.6	-2.06	2.63/2.34	4.4

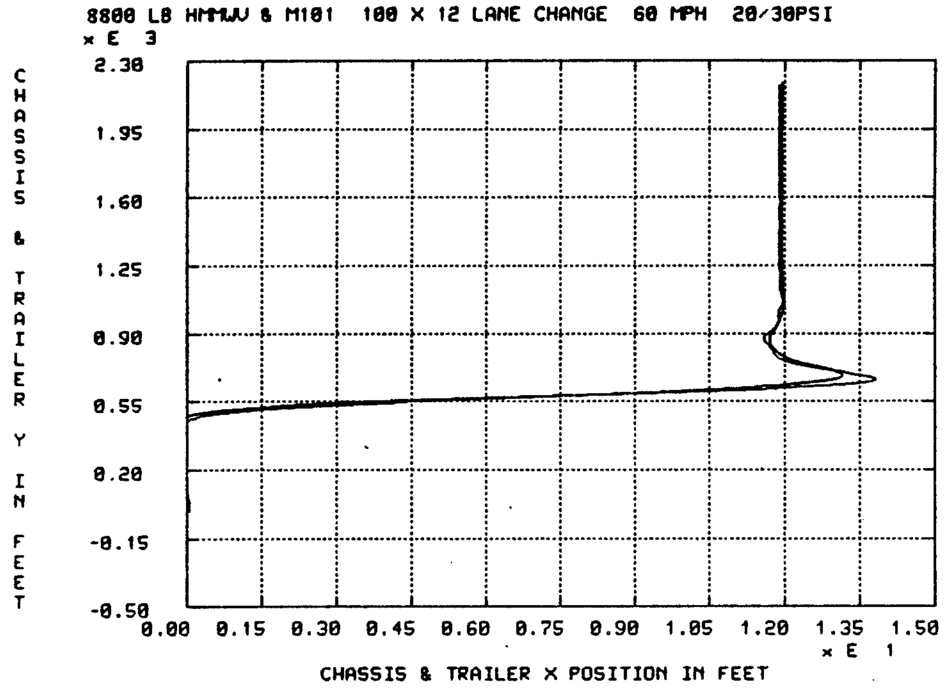

Figure 5.6.1-1 M1037/M101 CG position for a 100 ft by 12 ft 60 mph lane change.

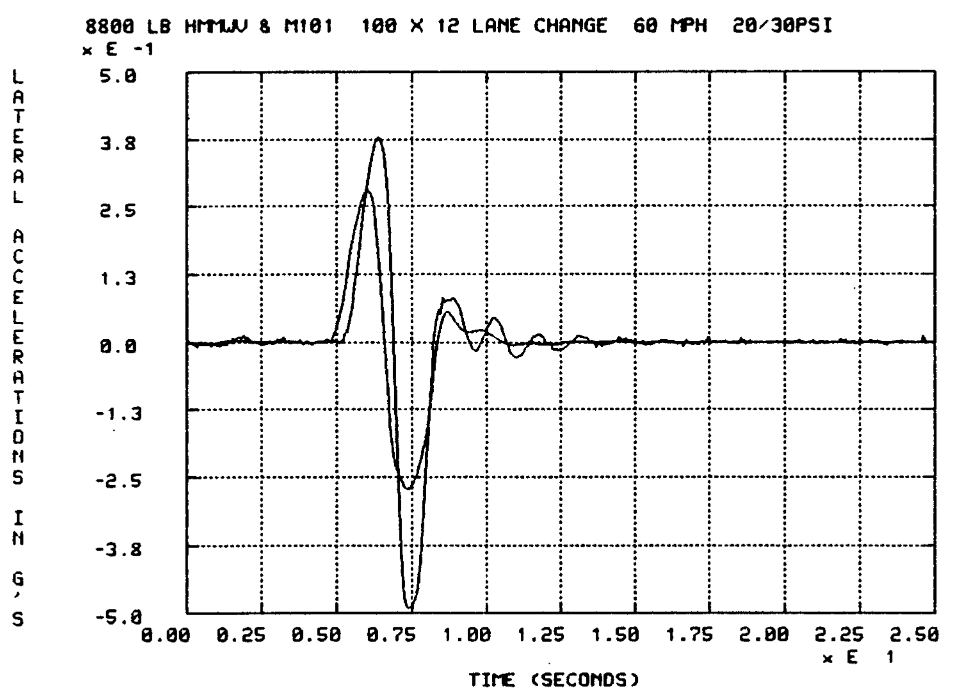

Figure 5.6.1-2 M1037/M101 CG Lateral acceleration of vehicle CG for a 100 ft by 12 ft 60 mph lane change.

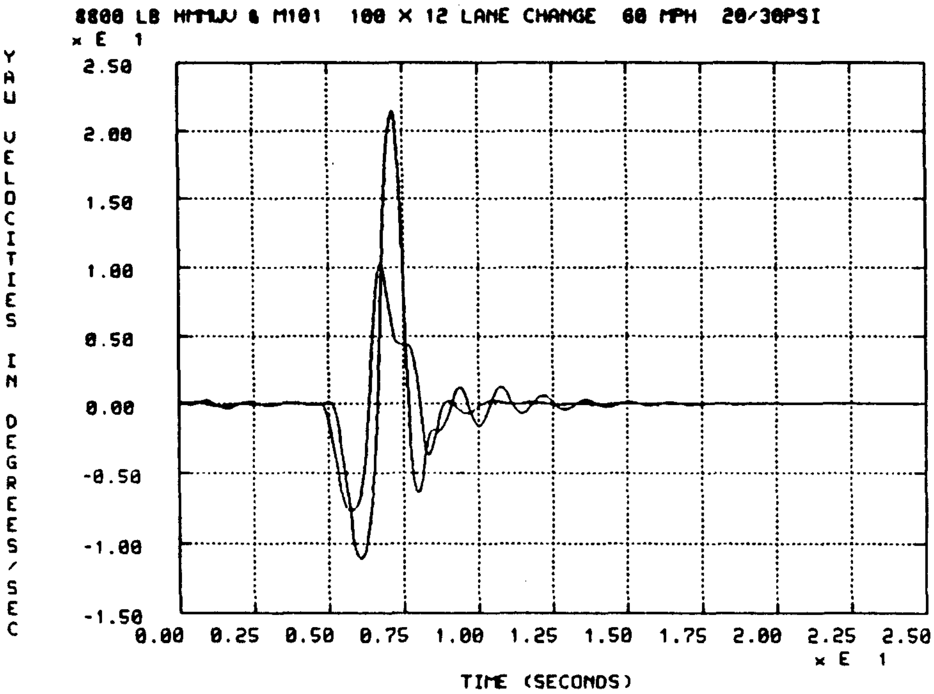

Figure 5.6.1-3 M1037/M101 yaw rate for a 100 ft by 12 ft 60 mph lane change.

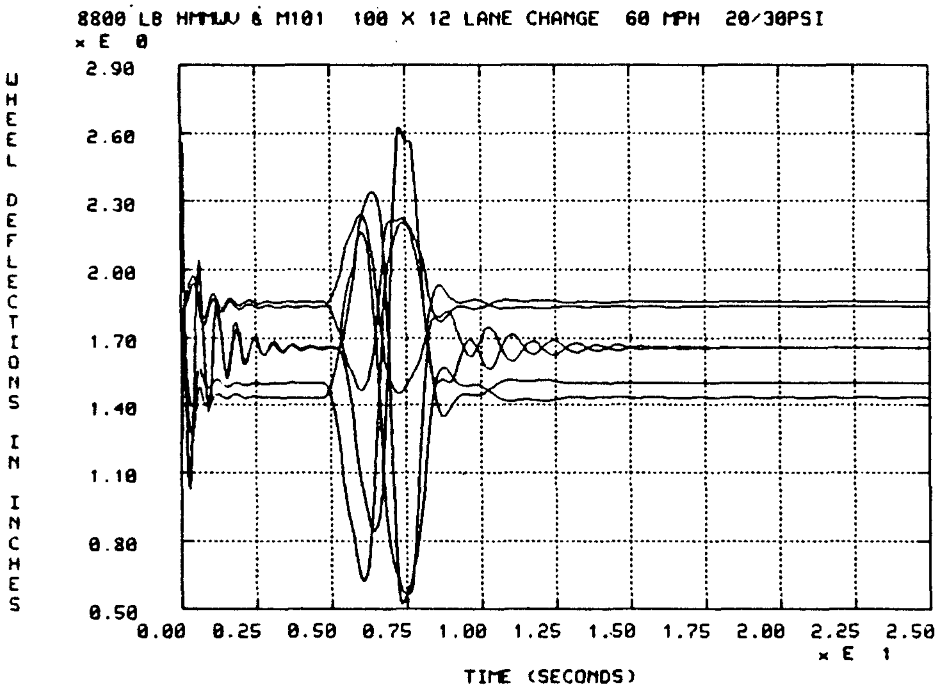

Figure 5.6.1-4 M1037/M101 vertical tire deflections for a 100 ft by 12 ft 60 mph lane change.

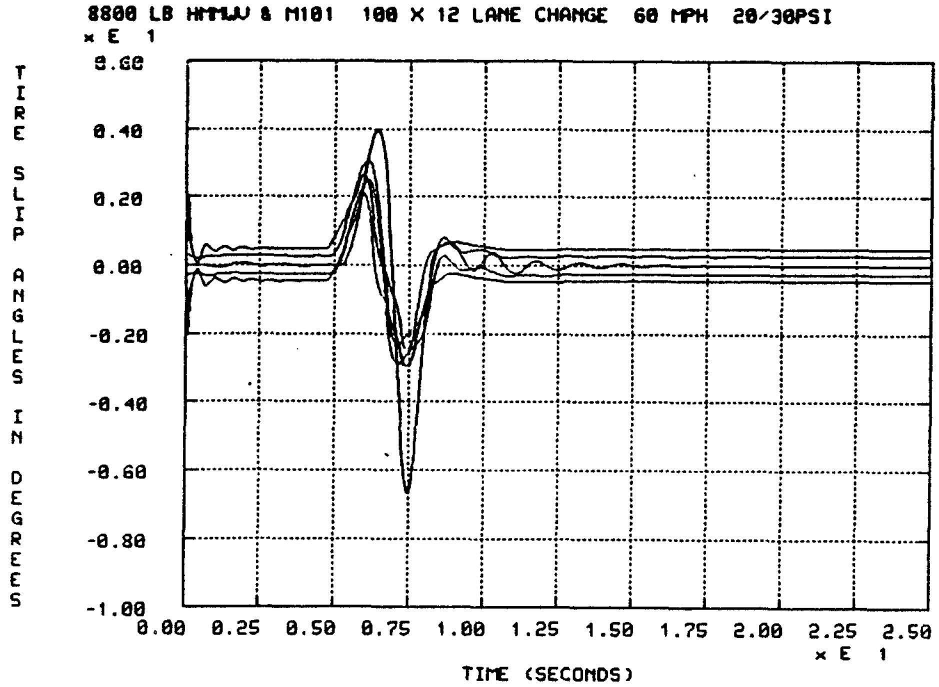

Figure 5.6.1-5 M1037/M101 tire slip angles for a 100 ft by 12 ft 60 mph lane change.

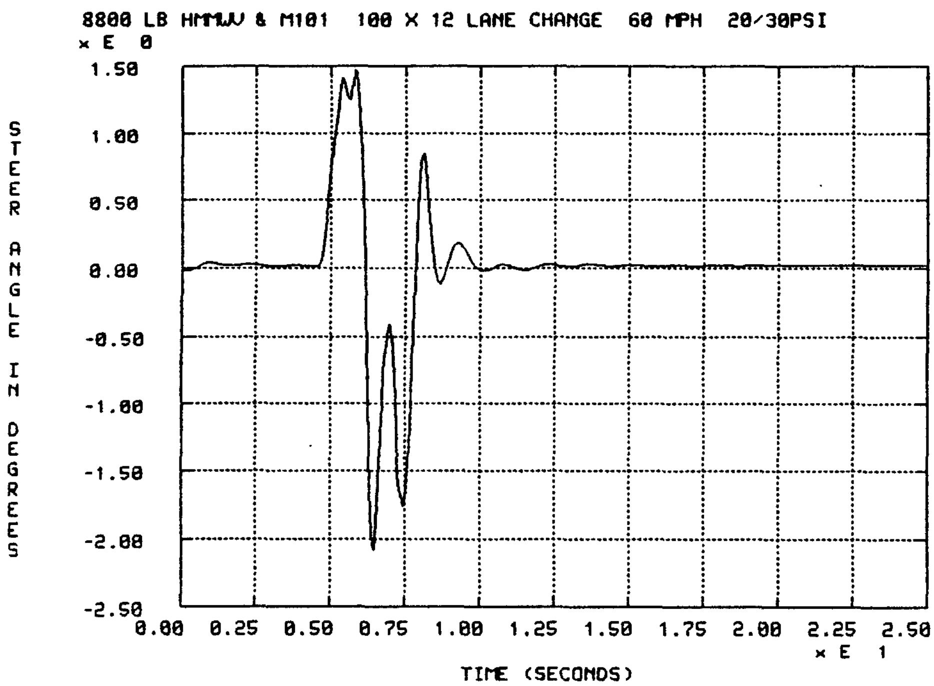

Figure 5.6.1-6 M1037/M101 steer angle for a 100 ft by 12 ft 60 mph lane change.

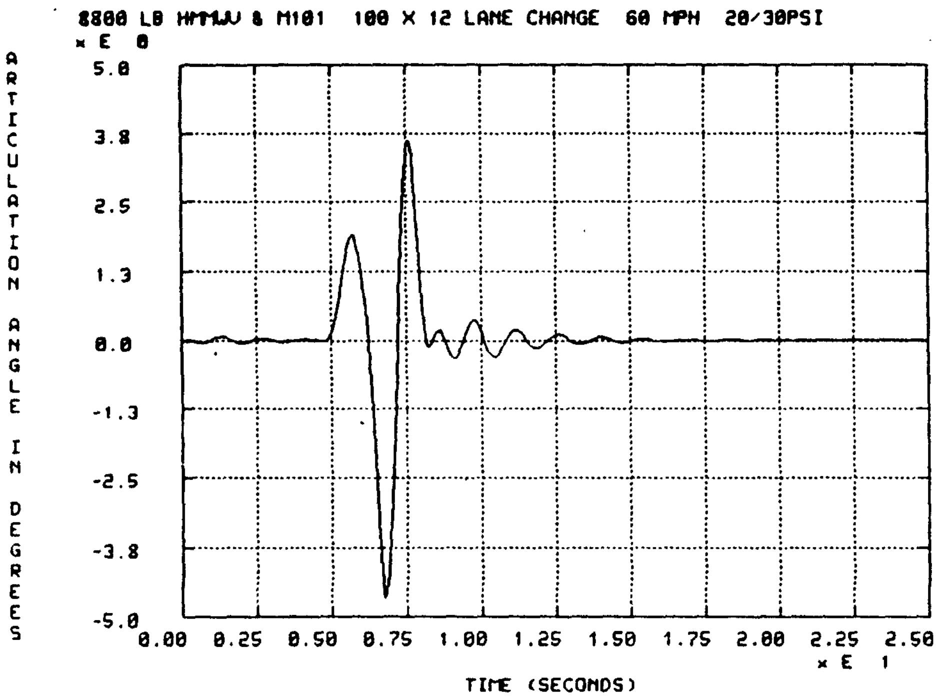

Figure 5.6.1-7 M1037/M101 articulation angle for a 100 ft by 12 ft 60 mph lane change.

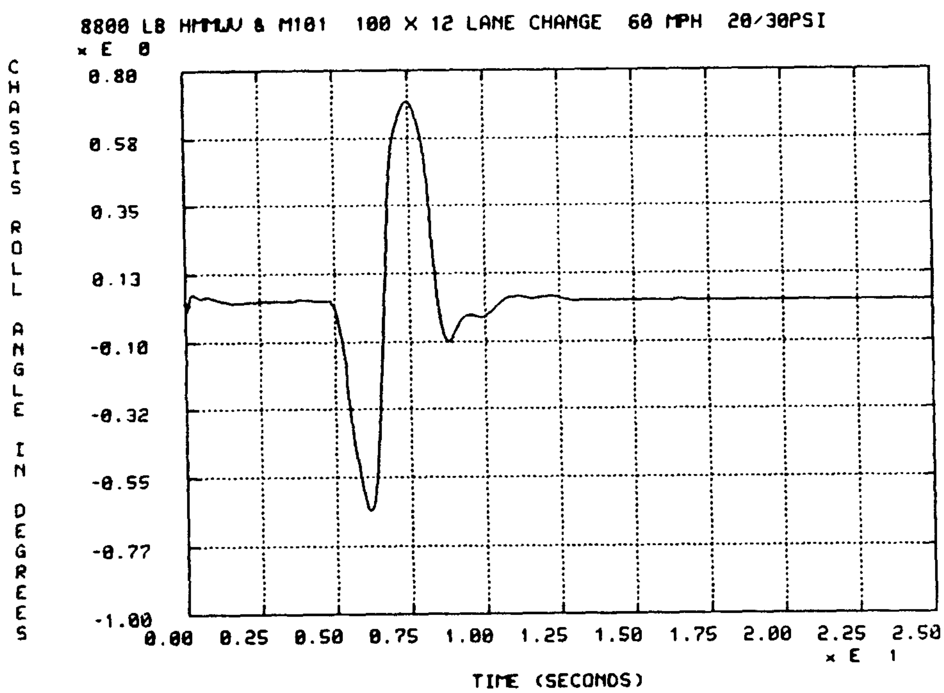

Figure 5.6.1-8 M1037/M101 roll angle for a 100 ft by 12 ft 60 mph lane change.

5.6.2. Steady Turn

In this part, the M1037/M101 system was required to perform a 500 foot radius steady turn maneuver. Figures 5.6.2-1 through 5.6.2-8 show the simulation results for a vehicle speed of 45 mph. At 50 mph the vehicle became unstable. Figure 5.6.2-8 shows the roll of the vehicle and trailer chassis relative to their respective suspensions. Note in Figure 5.6.2-4 that the front left tire deflection is close to zero indicating loss of traction in the front suspension. Results from the 50 mph simulation showed the front left tire lost traction completely. This phenomenon produced yaw divergence of the system, which eventually made the trailer roll over.

Table 5.6.2-1 Peak values for the M1037/M101 500 ft radius steady turn simulations.

Speed	Truck/Trailer Lateral Acc.	Truck/Trailer Yaw rate	Truck/Trailer Articulation angle	Steer	Truck/Trailer Tire Def	Truck/Trailer Tire slip
mph	g's	deg/s	deg	deg	inches	deg
25	0.090/ 0.099	-4.52/-4.55	1.38	1.38	1.94/2.57	1.3/ 0.67
40	0.278/ 0.302	-9.2/-10.2	2.0	2.4	2.55/2.55	2.89/ 2.92
45	0.309/ 0.403	-11.2/-12.8	2.28	4.15	2.56/2.35	4.90/ 4.05
50	(unstable)					

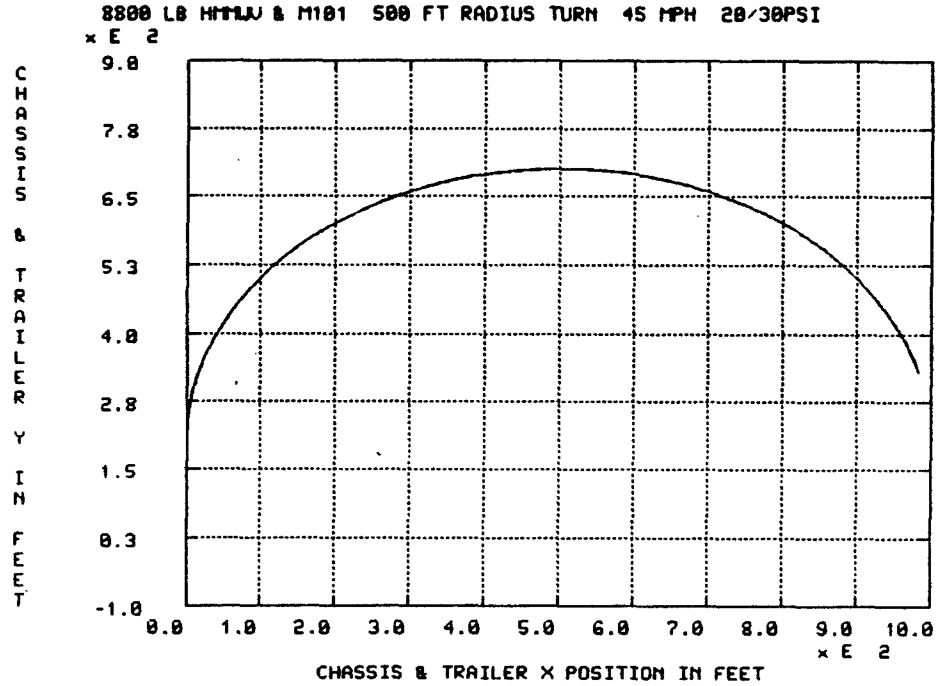

Figure 5.6.2-1 M1037/M101 CG position for a 500 ft radius steady turn simulation, 45 mph.

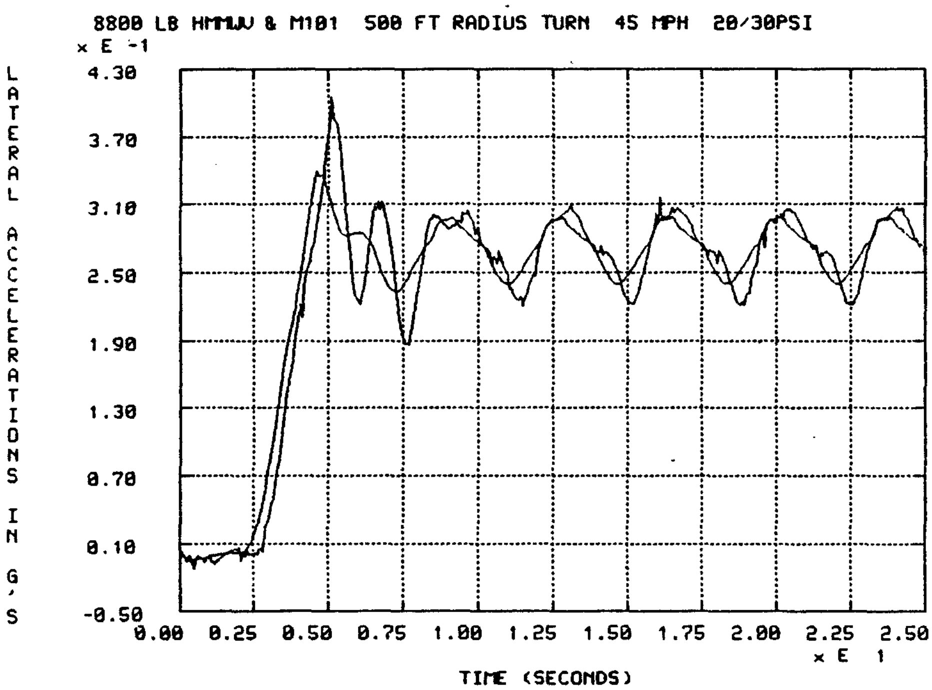

Figure 5.6.2-2 M1037/M101 CG Lateral acceleration of vehicle CG for a 500 ft radius steady turn simulation, 45 mph.

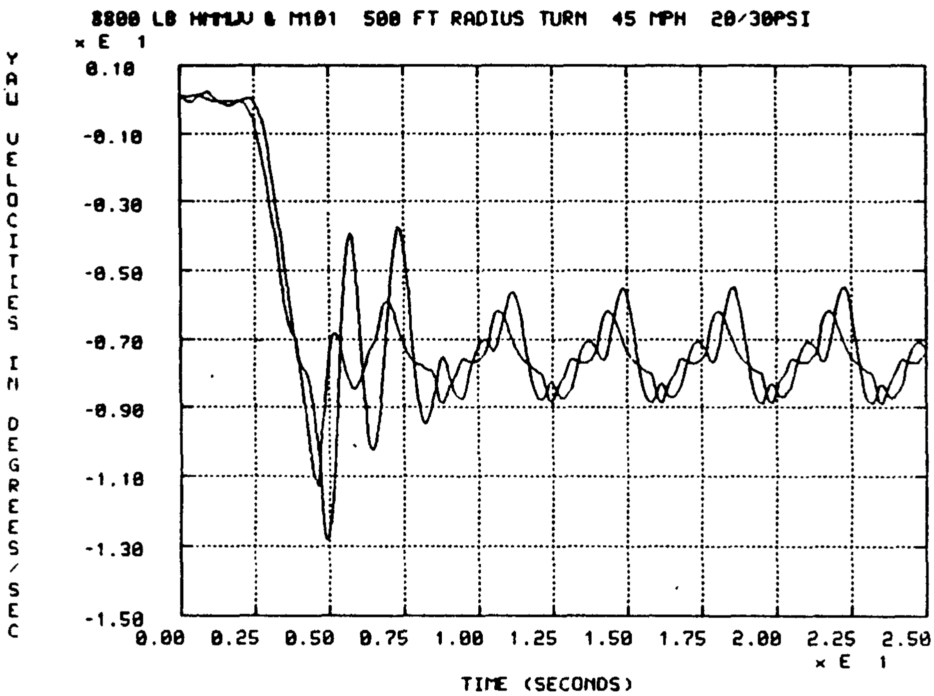

Figure 5.6.2-3 M1037/M101 yaw rate for a 500 ft radius steady turn simulation, 45 mph.

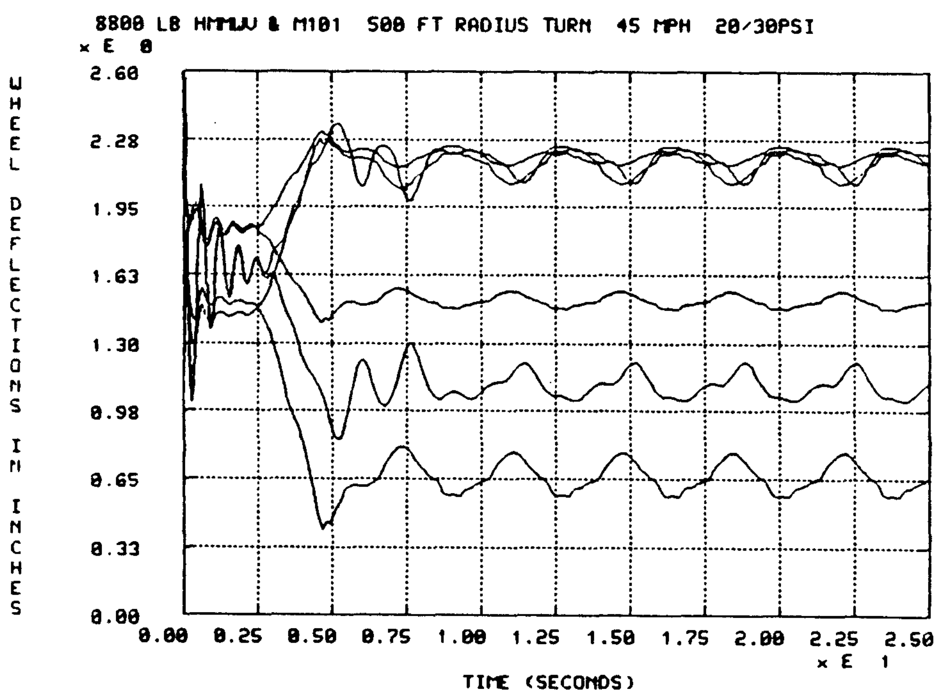

Figure 5.6.2-4 M1037/M101 vertical tire deflections for a 500 ft radius steady turn simulation, 45 mph.

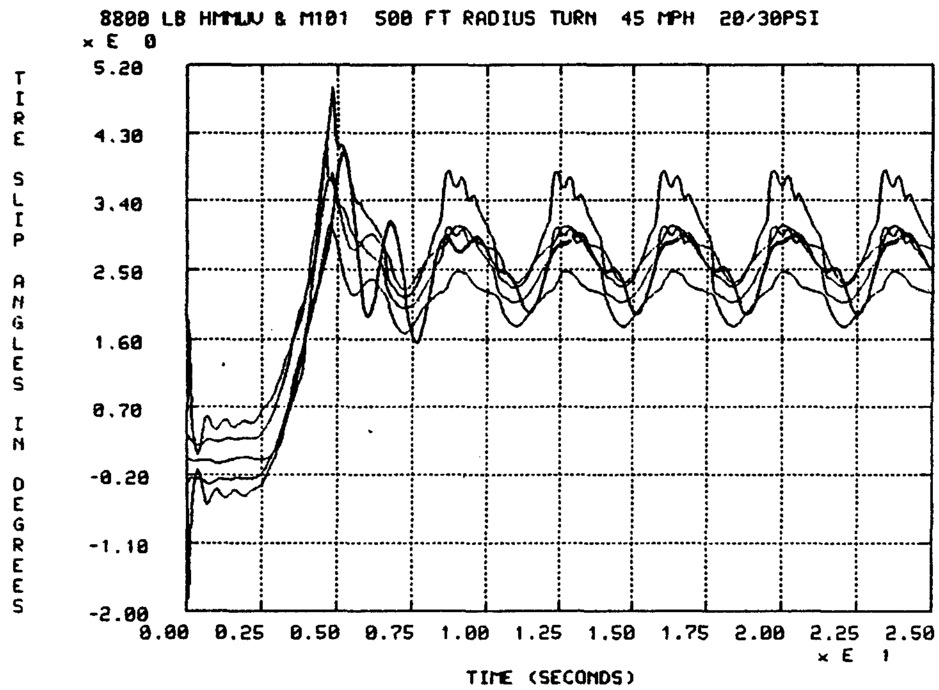

Figure 5.6.2-5 M1037/M101 tire slip angles for a 500 ft radius steady turn simulation, 45 mph.

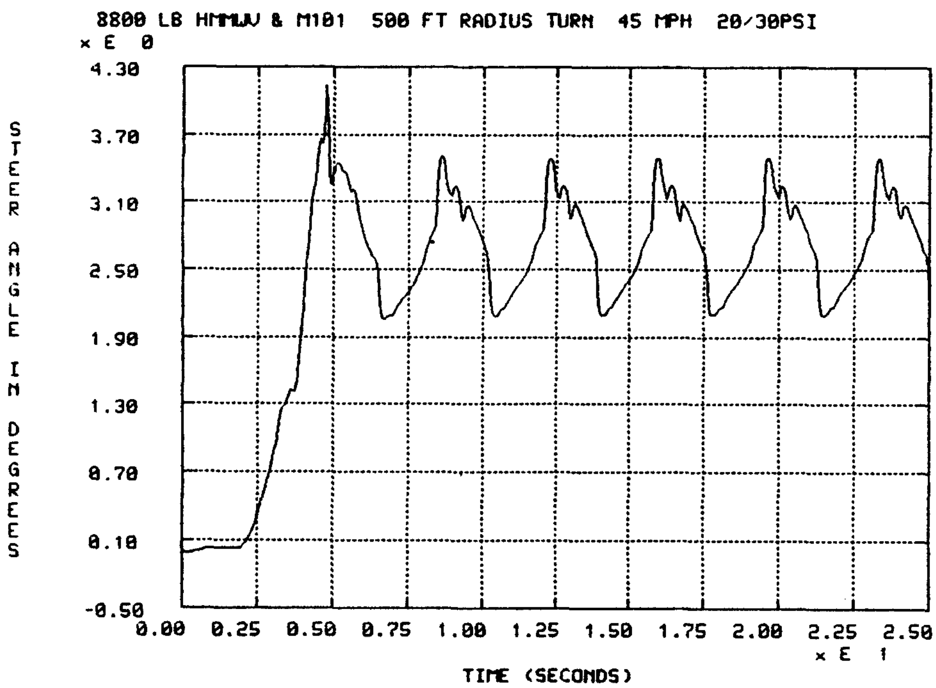

Figure 5.5.1-6 M1037/M101 steer angle for a 500 ft radius steady turn simulation, 45 mph.

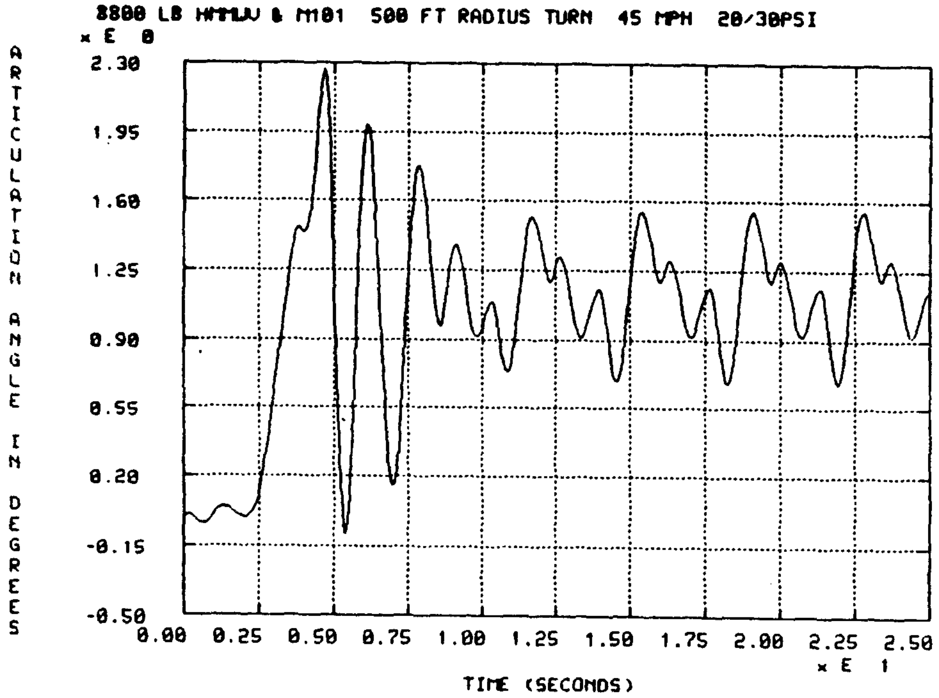

Figure 5.6.2-7 M1037/M101 articulation angle for a 500 ft radius steady turn simulation, 45 mph.

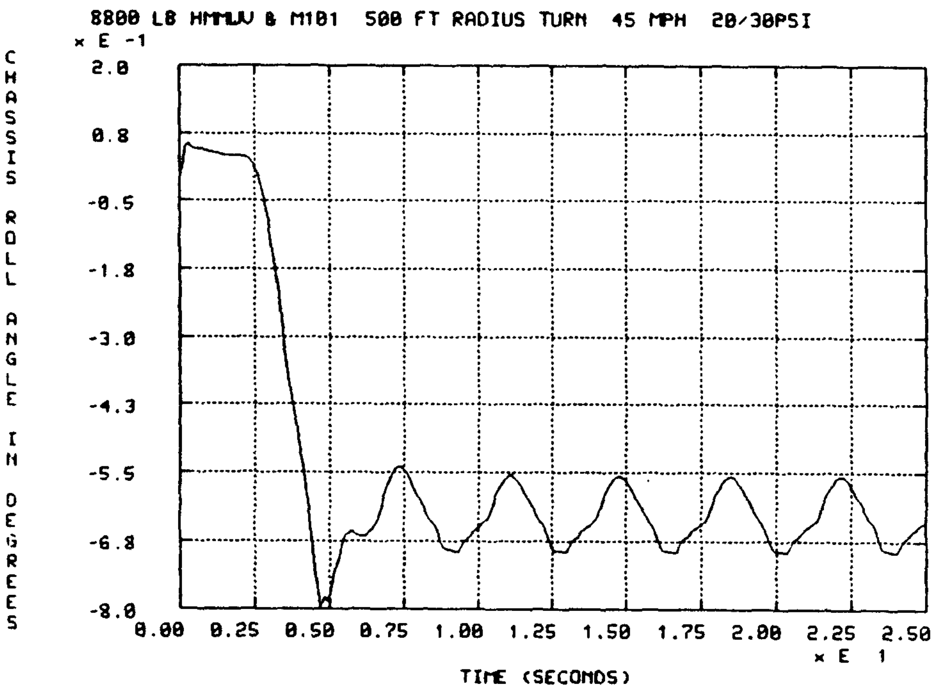

Figure 5.6.2-8 M1037/M101 Chassis roll angle for a 500 ft radius steady turn simulation, 45 mph.

5.6.3. Bump Course

In this part the M1037/M101 system was driven over the 6 inch bump course described in section 5.4. Table 5.6.3-1 shows the peak response values produced from the simulation. The simulation results showed that the vehicle could negotiate the bump course at speeds of up to 55 mph. However, Table 5.6.3-1 showed that the trailer response was violent at speeds of between 10 mph and 20 mph. This phenomenon was also observed in the validation tests described in section 5.4.2. Even though the simulation did not show that the trailer rolled over, there is still a good chance that the system may be unsafe for off road operation at speeds above 10 mph. Figures 5.6.3-1 through 5.6.3-9 show the results for 15 mph bump course simulation.

Table 5.6.3-1 Peak values for the M1037/M101 bump course simulations.

Speed	Truck/Trailer Lateral Acc.	Truck/Trailer Vertical acc.	Truck/Trailer roll	Articulation angle	Truck/Trailer Tire Def	Suspension roll
mph	g's	deg/s	deg	deg	inches	deg
10	-0.130/ 0.33	2.25/-5.5	-0.4/-7.85	-0.97	3.59/2.72	0.97
15	-0.090/ 0.475	3.4/-7.9	-1.4/-8.8	-1.62	3.53/2.55	1.13
20	0.110/ 0.46	3.9/ 9.8	-3.2/ 10.0	-2.2	3.75/2.78	1.32
25	0.100/ -0.5	-10.9/ 2.6	0.7/-7.1	-1.98	3.85/2.60	1.54
35	0.135/-0.495	-3.1/-13.5	0.65/-5.3	1.48	4.45/3.18	1.30
55	0.09/-0.54	-3.4/-9.7	-0.49/-4.18	1.34	4.72/2.55	1.02

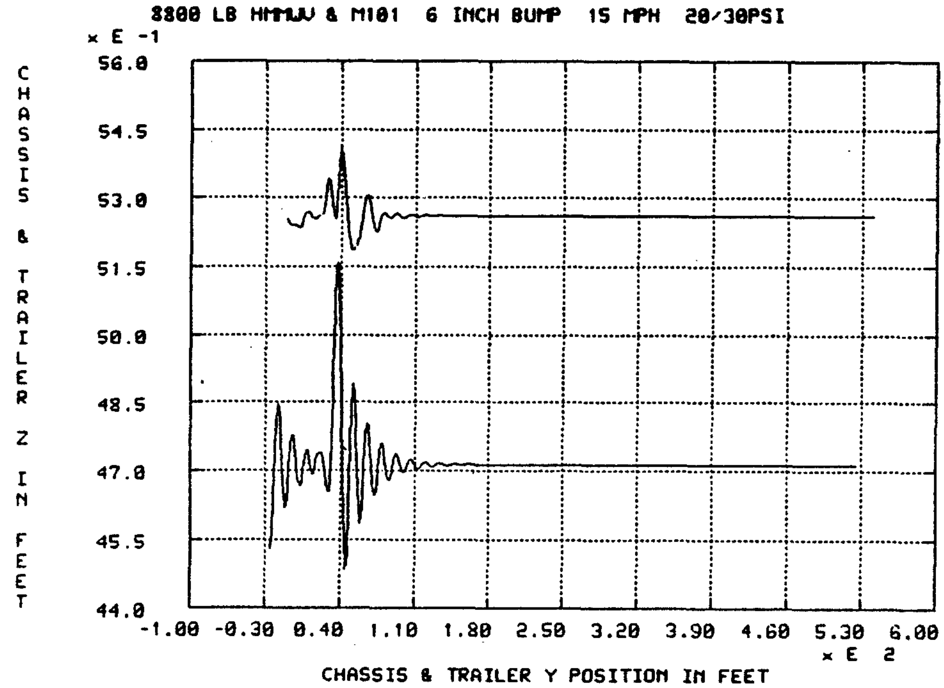

Figure 5.6.3-1 M1037/M101 CG position for the 6 inch bump course simulation, 15 mph.

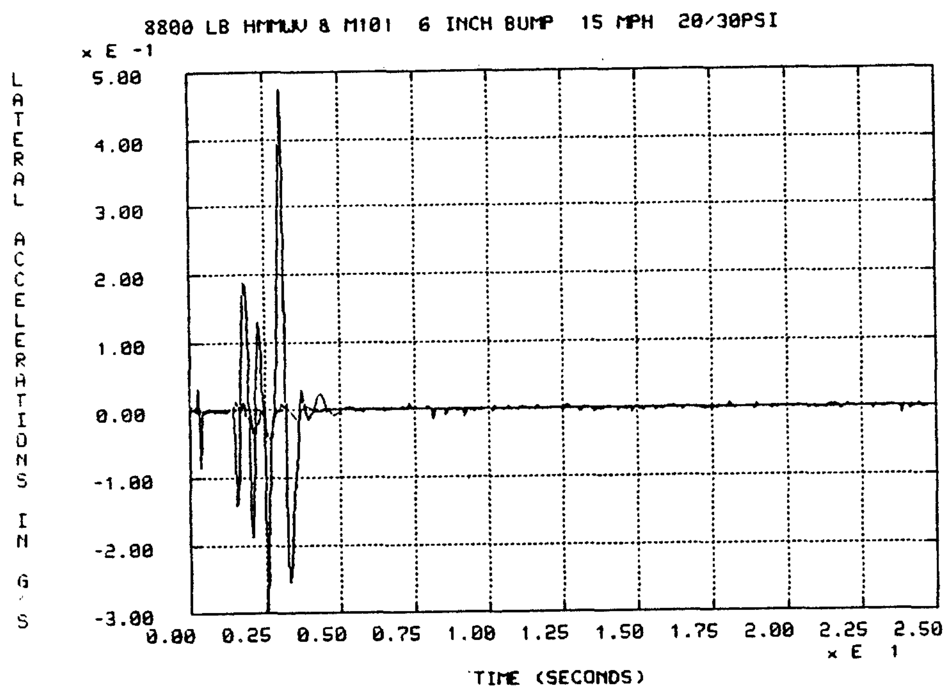

Figure 5.6.3-2 M1037/M101 CG Lateral acceleration of vehicle CG for the 6 inch bump course simulation, 15 mph.

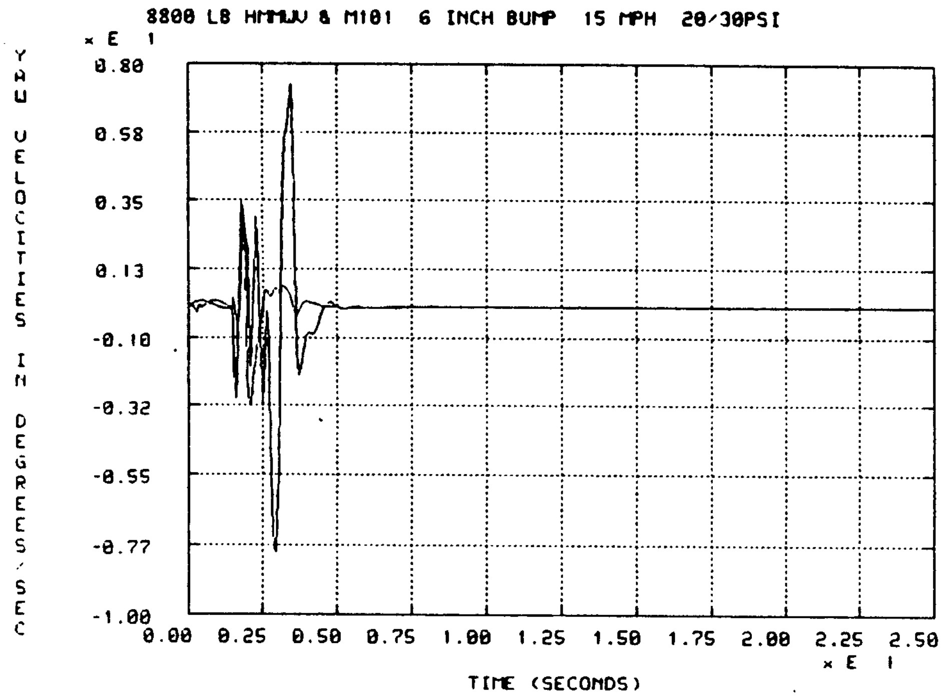

Figure 5.6.3-3 M1037/M101 yaw rate for the 6 inch bump course simulation, 15 mph.

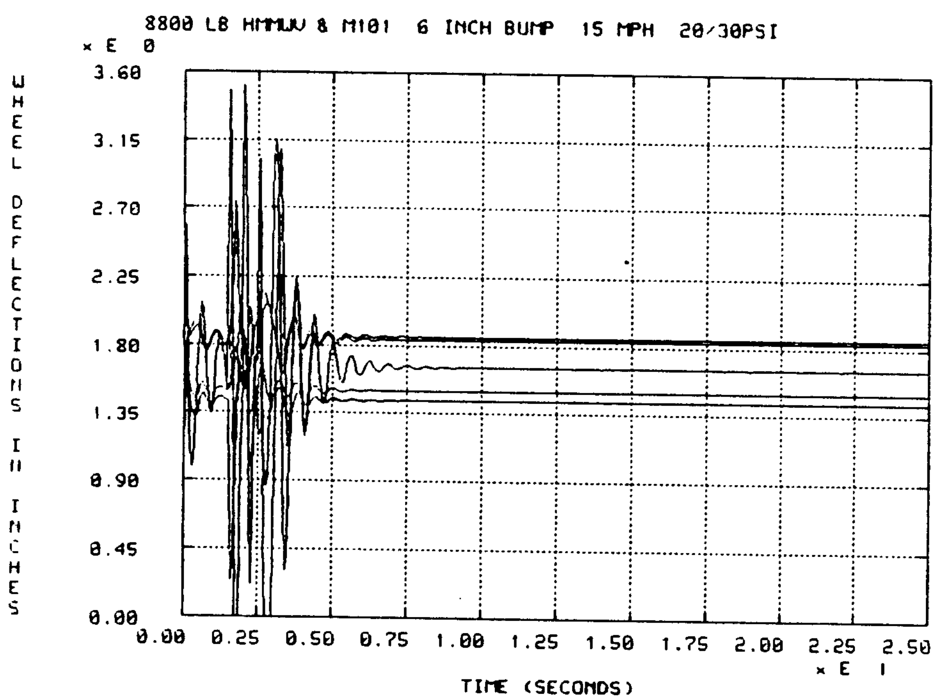

Figure 5.6.3-4 M1037/M101 vertical tire deflections for the 6 inch bump course simulation, 15 mph.

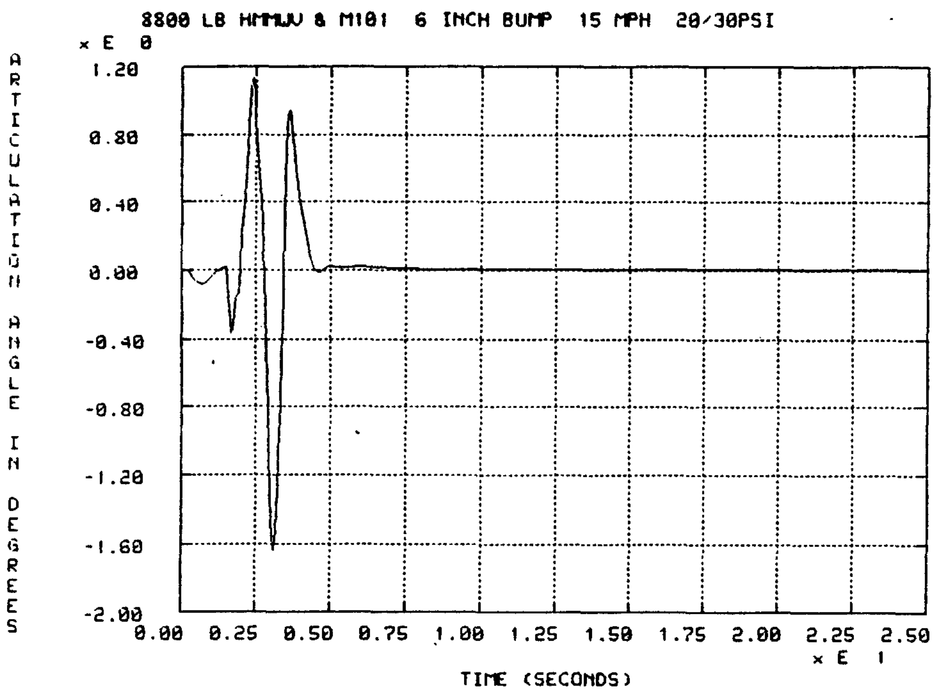

Figure 5.6.3-5 M1037/M101 articulation angle for the 6 inch bump course simulation, 15 mph.

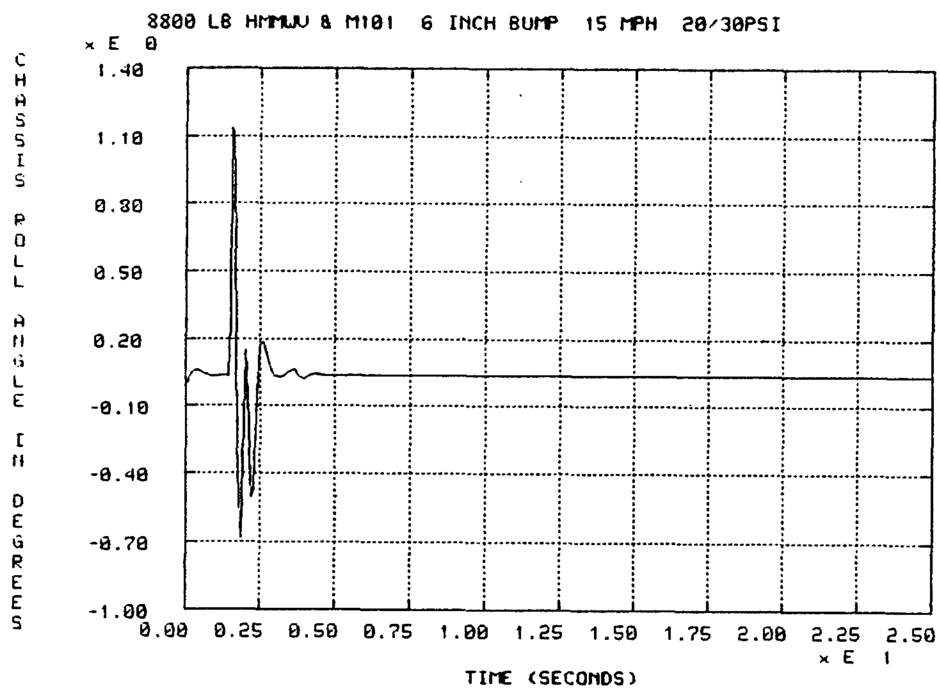

Figure 5.5.3-6 M1037/M101 chassis roll angle for the 6 inch bump course simulation, 15 mph.

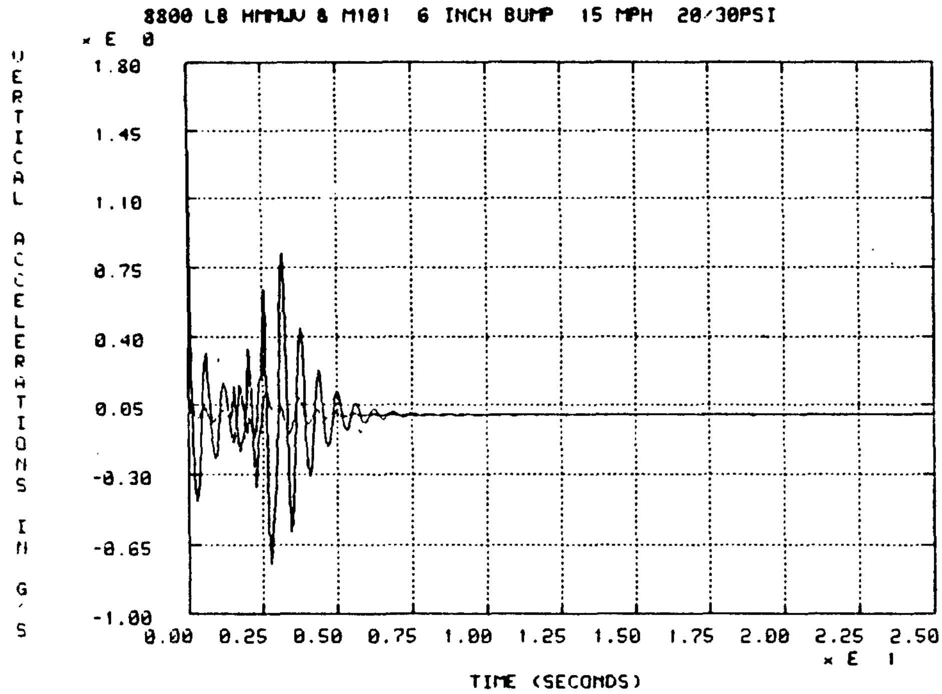

Figure 5.6.3-7 M1037/M101 chassis CG vertical acceleration for the 6 inch bump course simulation, 15 mph.

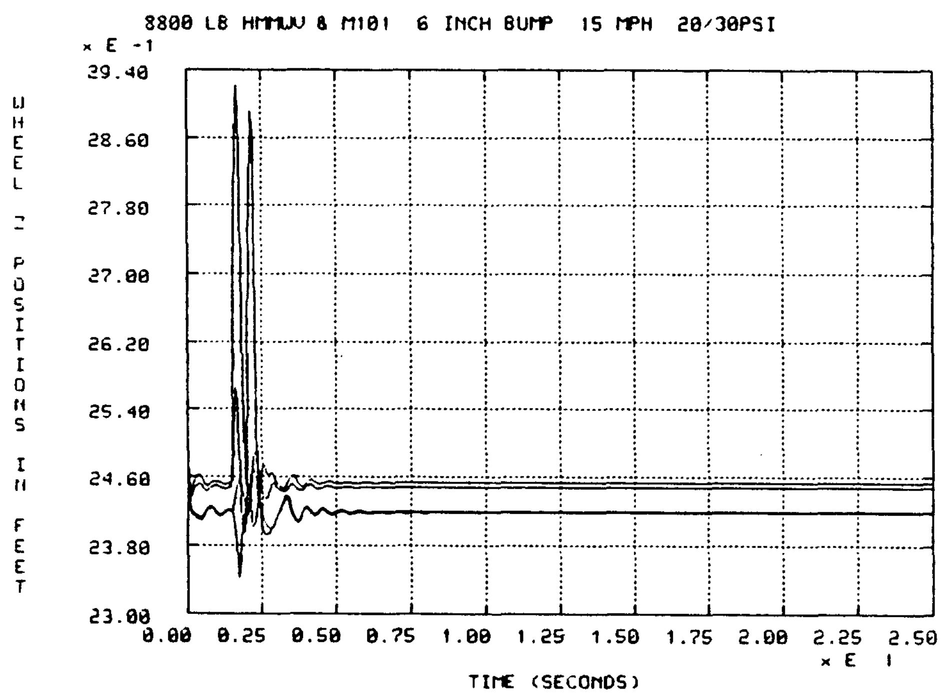

Figure 5.6.3-8 M1037/M101 vertical wheel position for the 6 inch bump course simulation, 15 mph.

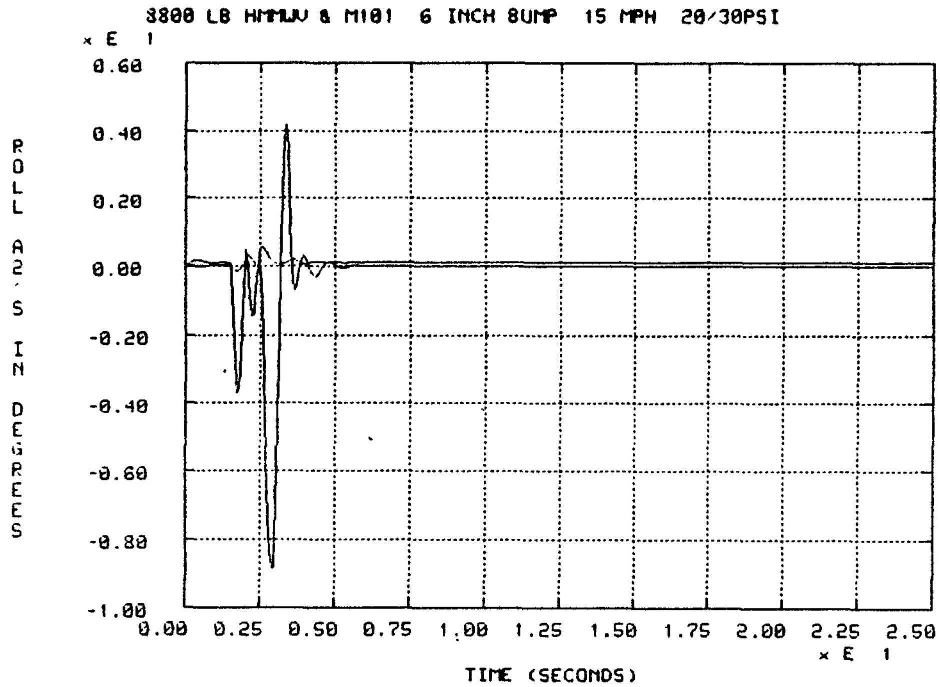

Figure 5.6.3-9 M1037/M101 chassis roll angle for the 6 inch bump course simulation, 15 mph.

5.5.4. Maneuvering on an Inclined Slope

In this part, the vehicle was subjected to a 100 ft by 12 ft lane change maneuver on down hill grades of 15% and 29%. Table 5.6.4-1 shows the peak values of the simulation results. The 15% down hill slope results showed no instability. However, they did show slightly higher peak response values. Compare the values in tables 5.6.4-1 and 5.6.1-1. The 29% down hill simulations exhibited more unusual behavior. Out of all the simulation runs conducted on the 29% slope, the 15 mph showed the highest peak dynamic response.

Table 5.6.4-1 Peak values for the M1037/M101 inclined slope lane change simulations

Speed	Course	Truck/Trailer Lateral Acc.	Truck/Trailer Yaw rate	Truck/ Trailer Art. angle	Steer	Truck/Trailer Tire Slip
mph		g's	deg/s	deg	deg	deg
25	15% DH LC	-0.116/-0.138	6.2/ 6.9	-2.08	-2.0	2.42/ 1.1
60	15% DH LC	-0.221/-0.365	2.56/ 2.34	3.55	-2.68	-4.4/-3.8
15	29% DH LC	-0.300/ 0.430	11.0/ 19.0	5.0	12.0	-
25	29% DH LC	-0.335/-0.255	-9.8/ 16.1	-3.15	-10.9	-12.1/2.8
60	29% DH LC	0.178/0.244	-4.1/-7.6	-1.81	3.29	4.81/2.89

5.7. Analytical results

5.7.1. Yaw Plane Modeling

For this analysis, the vehicle is assumed to experience only planar motion. Only yaw, lateral, and fore-aft motion of the system is allowed. Roll, pitch and vertical motion is not considered to take place. Figure 5.7.3-1 shows a plane view of a two axle truck towing a single axle trailer. This Figure shows a system which has four degrees of freedom, including the forward, lateral, and yaw motion of the truck, and the articulation of the trailer with respect to the truck.

The tire behavior in the yaw plane case is simpler than the spatial mode presented in section 5.1. The vertical tire load, aligning moment, and traction forces are neglected. Furthermore, in the spatial case, the tires' lateral force characteristics are a function of vertical load, while the yaw plane approach assumes the lateral force is only dependent upon the slip angle and it is independent of the vertical force. This assumption limits the application of yaw plane to quasi-static situations, i.e., straight line motion or fixed radius turns at a steady speed.

The yaw plane dynamic equations of motion for the truck/trailer system are derived in [9]. The general form of the equations is

$$\mathbf{M}(\mathbf{q})\,\dot{\mathbf{u}} = \mathbf{g}(\mathbf{u},\mathbf{q}) \tag{5.7.1-2}$$

were **M** is the n by n system mass matrix, **g** is the continuously differentiable nonlinear function of generalized and velocity dependent forces of dimension n, **u** is the generalized speed vector of dimension n, and **q** is the vector of generalized coordinates. Another form for equation (5.7-1) is

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}) \tag{5.7.1-3}$$

were $\mathbf{f}(\mathbf{x}) = \mathbf{M}^{-1}(\mathbf{x})\,\mathbf{g}(\mathbf{x})$, and the state vector $\mathbf{x} = [\mathbf{q}\ \mathbf{u}]^T$.

5.7.1. Inaccuracies

Possible sources of error in this analysis include: change in tire lateral force properties resulting from load transfer between tires, and nonlinear coupling between planar and neglected out of plane coordinates. The former item probably has the greatest influence on vehicle response. MacAdam [10] has shown that the nonlinear sensitivity of the truck tire cornering stiffness can contribute to yaw divergent behavior of a vehicle. Furthermore, a high vehicle center of gravity coupled with a

low roll center can produce a large amount of load transfer between tires on an axle, altering the lateral force characteristics of a tire. This change in tire behavior will modify the dynamics of the vehicle. Nominally, the vehicle equations of motion developed under the yaw plane assumptions do not allow for the phenomenon mentioned above, and thus can reach erroneous conclusions if one is not careful.

5.7.2. Linearized Equations

The most commonly used analytical method for examining the stability of a nonlinear system utilizes linearization. In this approach, the stability of small perturbations about an equilibrium point in state space is examined. The equilibrium point can be a static equilibrium, i.e. stationary object, or a quasi-static equilibrium point, i.e. vehicle traveling at a constant speed in a constant radius turn. Provided the function **f** in equation (5.7.1-2) is continuously differentiable, the following linearized form exists.

$$\dot{\mathbf{x}} = \mathbf{A}\,\mathbf{x} \tag{5.7.2-1}$$

where, **x** represents the vector of perturbations about an equilibrium point in state space, and the n by n matrix **A** is the given by

$$\mathbf{A} = \frac{\partial\,\mathbf{f}(\mathbf{x})}{\partial\,\mathbf{x}} \tag{5.7.2-2}$$

A theorem from nonlinear systems analysis, Liapunov's first method [11], states that if the function **f** is continuously diffrentiable, an equilibrium point **0** is stable if eigenvalues of **A** have all negative real parts[1]. Likewise, if the matrix **A** has at least one eigenvalue with one positive real part then the system is unstable. Since equation (5.7.1-2) is continuously differentiable, all the necessarily requirements for Liapunov's first method are met. Therefore, the quasi-static yaw stability of the vehicle and trailer system can be determined by examining the eigenvalues of **A** .

Figure 5.7.3-1 shows how the eigenvalues of A are distributed in the complex plane. Associated with each eigenvalue is a modal vector that describes a fundamental motion. The modes that are of primary interest in this analysis are the jackknife and trailer oscillatory modes. The vehicle configuration that corresponds to the jackknife mode is shown in Figure 5.7.2-1. The oscillatory mode shown in Figure 5.7.2-2, represents an oscillation of the vehicle and trailer about the hitch.

1 There is no loss of generality with an equilibrium point of **0**, since the state vector **x** can be redefined as $\mathbf{z} = \mathbf{x} + \mathbf{x}^*$,where $\mathbf{x}^*$ is the equilibrium point, and $\mathbf{f}(\mathbf{x},\mathbf{u})$ can be redefined as $\mathbf{f}(\mathbf{z} - \mathbf{x}^*,\mathbf{u})$.

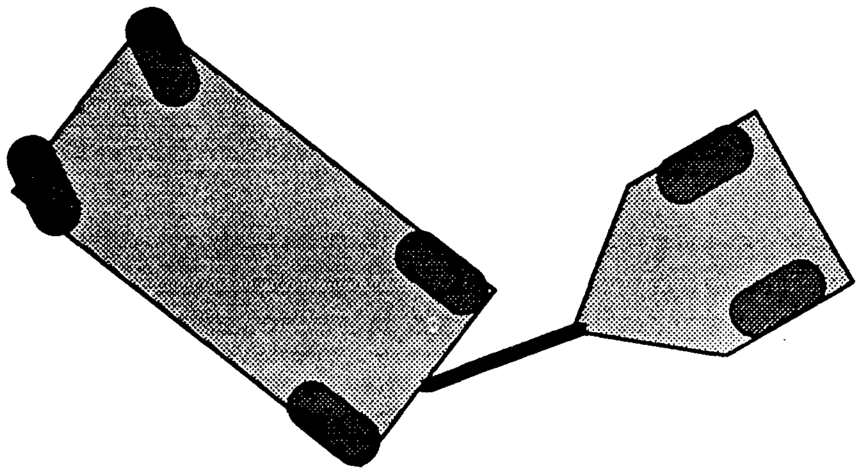

Figure 5.7.2-1 Yaw plane jackknife mode.

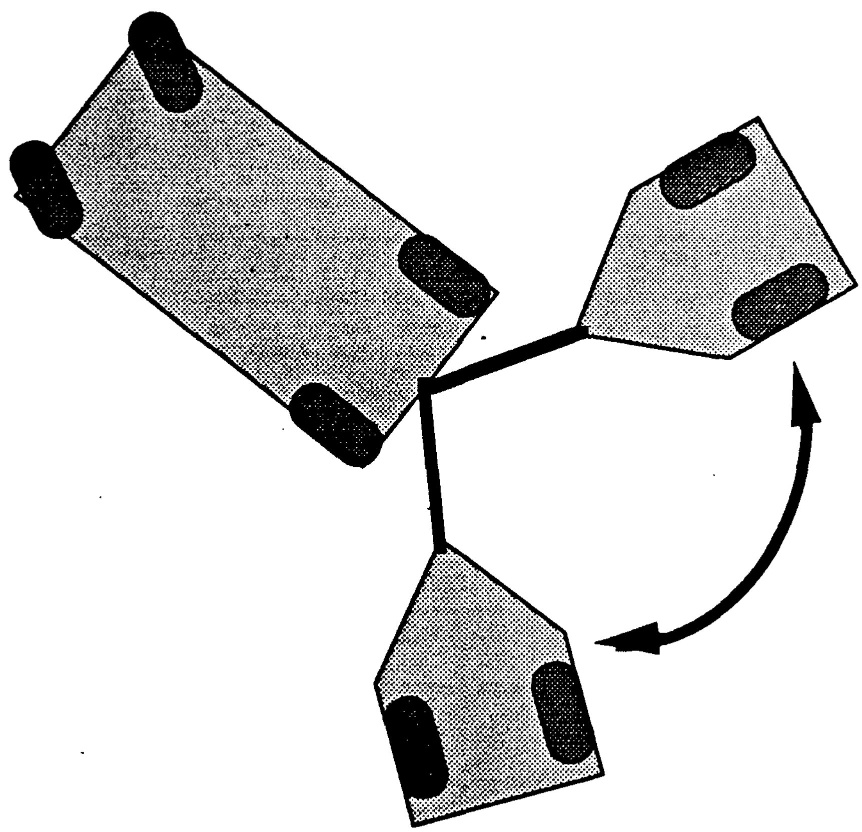

Figure 5.7.2-2 Yaw Plane articulation oscillatory mode.

5.7.3. Vehicle Stability During Forward Travel

The eigenvalues for the M1037/M101 were evaluated for straight line motion. Figure 5.7.3-1 shows the position of the eigenvalues in the complex plane. This Figure shows how the modes of oscillation move toward the right half plane as the vehicle's speed increases. Figure 5.7.3-2 shows how the damping ratio of the articulation mode decreases with increasing vehicle speed. A small amount of movement of the jackknife mode into the right half plane can be tolerated, since that mode can be controlled by the steering of the driver. However, the driver has no effective control of the articulation mode, and therefore any excitement of that mode may cause excessive trailer whip or produce vehicle instability.

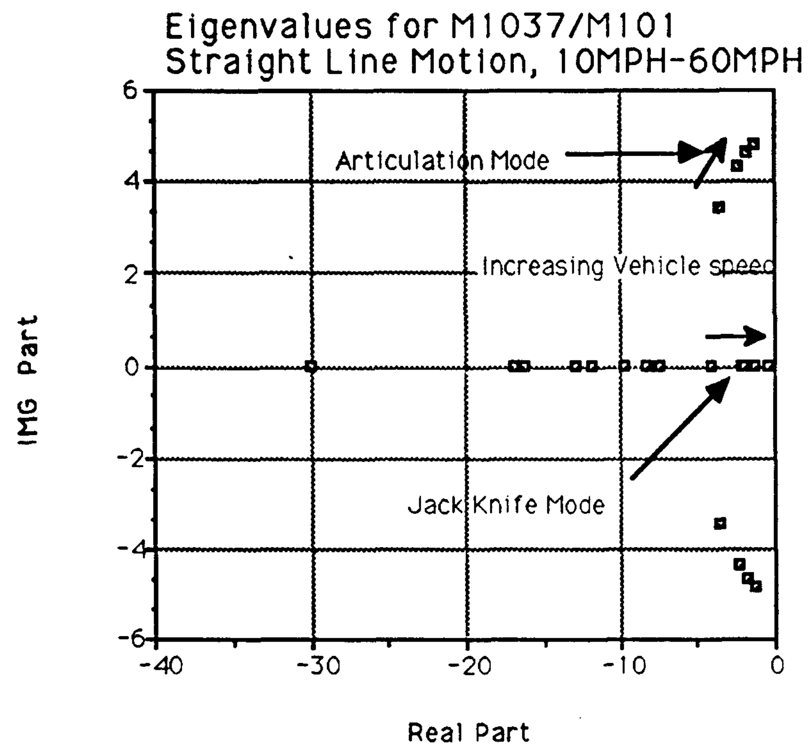

Figure 5.7.3-1 M1037/M101 eigenvalues during straight line motion.

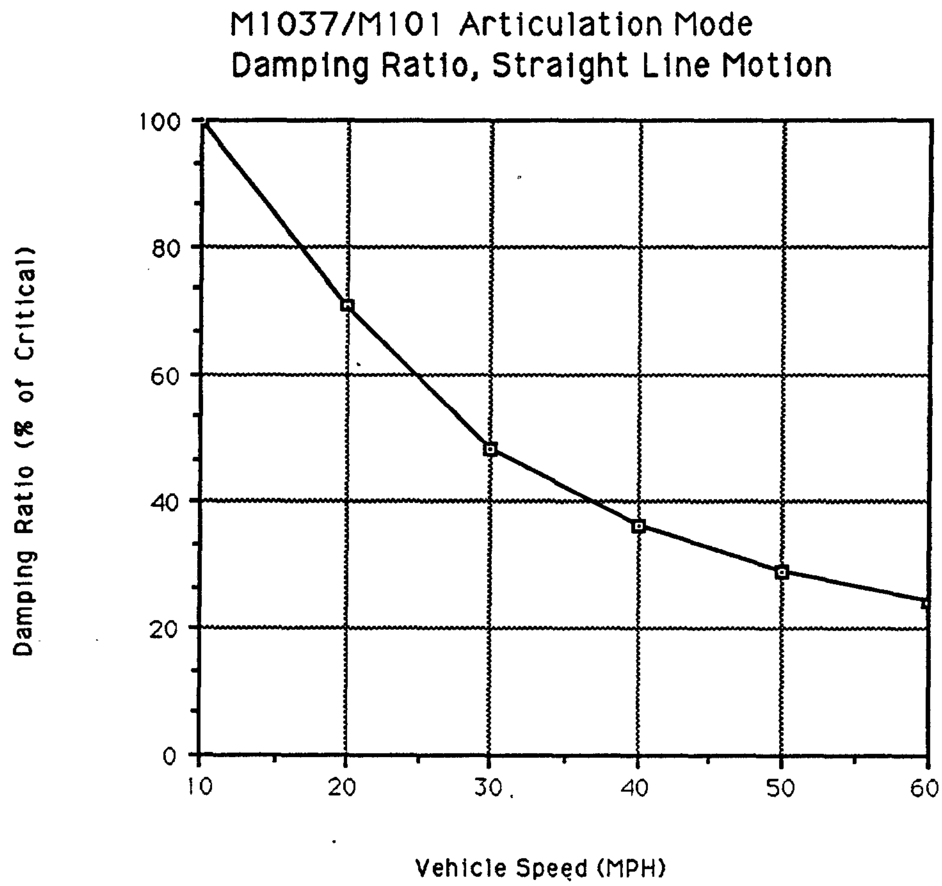

Figure 5.7.3-2 M1037/M101 articulation mode damping ratio during straight line motion.

The speed of instability predicted by the Yaw Plane model (higher than 60 mph) is greater than the speed arrived at from the multibody dynamic simulation results described in section 5.6. An explanation of why the current Yaw Plane model will not provide accurate results is presented in section 5.7.1. In the case of the M1037/M101 system, the rearward position of the vehicle CG makes the front suspension susceptible to load transfer between the front tires. Since the yaw plane model does not account for any type of load transfer between the tires, it can not predict any sort of traction loss which could produce instability. However, the Yaw plane model does provide a upper bound on the safe vehicle speed for straight line constant speed operation, and can generate very accurate results for low CG systems.

5.8. Vehicle braking

Braking tests were performed for both the truck alone and for the truck/trailer. Both straight line braking and braking in a 500 ft radius were conducted for the M1037. Braking in a 500 ft radius turn was conducted for the M1037/M101 system. All tests were performed on flat, dry pavement . No studies of vehicle braking were performed on inclined slopes or on wet payment.

During each test, barrier cones were set up at between 125 and 200 ft from a marked line that indicated the start of braking. As with the lane change and 500 ft radius maneuvers, the driver had to maintain the vehicle in 12 foot corridor that was marked with cones. The driver had to both initiate braking at the start line and to stop short of the barrier cones. The tests were repeated several times (between 5 and 14) with the barrier cones positioned at random distances between 125 and 200 ft. The cones were moved when the driver was out of viewing range. This precaution prevented the driver form anticipating barrier cone placement.

5.8.1. M1037 Braking Results

Table 5.8.1-1 presents the straight line braking test results. All tests were performed on level, dry pavement, and the brakes were not inspected for wear or adjustment. No vehicle instability was observed in any of the tests.

Table 5.8.1-1 Results from M1037 braking tests.

Test ID	Speed	Comments
203	50	Straight braking, 143 ft stopping distance.
204	50	Straight braking, 120 ft stopping distance, short brake lock front, and rear.
205	50	Straight braking, 170 ft stopping distance.
206	50	Straight braking, 195 ft stopping distance.
207	50	Slight vehicle draft to right, 130 ft stopping distance, all locked. Brake locking started 14 ft into maneuver.
208	50	Straight braking, 140 ft stopping distance.
209	50	Straight braking, 150 ft stopping distance.
210	50	Straight braking, 200 ft stopping distance, slight brake lock at end.
211	50	Straight braking, 170 ft stopping distance
212	50	Straight braking, 150 ft stopping distance.
213	50	Straight braking, 200 ft stopping distance.
214	50	Straight braking, 125 ft stopping distance, front and rear brakes locked.
215	50	Straight braking, 145 ft stopping distance.
216	50	Straight braking, 175 ft stopping distance.

5.8.2. M1037/M101 Braking Results

Table 5.8.2-1 shows the results from the 500 radius turn braking tests. A reaction brake was installed and was operational in the trailer provided for these tests. No vehicle instability was observed during the braking tests. All tests were conducted on level, dry payment.

Table 5.8.2-1 Results from the M1037/M101 braking tests.

Test ID	Speed	Comments
303	45	180 ft stopping distance, one wheel locked up.
304	45	220 ft stopping distance.
305	50	170 ft stopping distance.
306	50	180 ft stopping distance, vehicle locked up all four brakes. Over 50 ft of skid marks.
307	50	143 ft stopping distance.
308	50	169 ft stopping distance.
309	50	147 ft stopping distance. Intermittent brake lockup, 25 ft of skid marks.
310	48	145 ft stopping distance.

LIST OF REFERENCES

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[9] MacAdam, C. C., "Application of an Optimal Preview Control for Simulation of Closed-Loop Automobile Driving," *IEEE Transactions on Systems, Man, and Cybernetics,* Vol. SMC-11, No. 6, June 1981.

[10] MacAdam, C. C., "Development of Driver/Vehicle Steering Interaction Models for Dynamic Analysis," Interim Technical Report Contract DAAE07-85-C-R069, University of Michigan Transportation Research Institute, July 1986.

[11] Vidyasagar, M., *Nonlinear Systems Analysis*, Prentice Hall, Englewood Cliffs, N.J., 1978.

APPENDIX A

Test Plan for Road Testing

UMTRI
The University of Michigan
Transportation Research Institute
2901 Baxter Road, Ann Arbor, Michigan 48109-2150

March 30, 1988

U.S. Army Tank-Automotive Command
AMSTA-ZSA Attn: Mr. Ric Mousseau
Warren, MI 48397-5000

Subj: Development of Driver/Vehicle
Steering Interaction Model for
Dynamic Analysis, DAAE07-85-C-R069

Dear Mr. Mousseau:

Enclosed with this letter for your review and approval is a copy of the Vehicle/Driver Test Plan for upcoming tests of the HMMWV to be performed at the Chrysler Proving Grounds. Also enclosed is a revised set of charts updating the planned expenditures for the project through its completion in September. An additional $15,000 of project funding is included in these projections to cover the costs of the trailer testing and other analyses you requested. The May expenditures include an estimate of approximately $7000 (including University indirect costs) for renting the Chrysler Proving Grounds (Vehicle Dynamics Facility) for about 6 full days.

Sincerely yours,

Charles C. MacAdam

Charles C. MacAdam
Project Director

xc: D. M. Maxinoski
J. Thomson
R. Ervin
P. Fancher
C. Winkler

Vehicle / Driver Test Plan

Task A -- Instrumenting and Preparation of the Test Vehicle

The test vehicle will be the four-wheeled HMWWV operating in a low center-of-gravity configuration. A small payload will be carried to help locate the fore-aft position of the vehicle center-of-gravity. The vehicle will be instrumented with appropriate transducers and the UMTRI data acquisition package to measure the following signals and vehicle responses:

- Lateral Acceleration
- Longitudinal Acceleration
- Vehicle Velocity
- Yaw Rate
- Roll Rate
- Front Wheel Steer Angle(s)
- Steering Wheel Angle
- Brake Pedal Pressure

The UMTRI stable platform will be used to measure the lateral and longitudinal accelerations as well as the yaw and roll rates. A conventional fifth wheel will be used to measure forward velocity. Front wheel angles will be measured with linear potentiometers; driver steering wheel angle with a rotary potentiometer; and driver brake pedal force with an hydraulic pressure transducer.

Task B -- Vehicle Weight & Length Measurements

The HMMWV will be weighed in its test condition (with instrumentation and two passengers) to obtain front and rear tire loads and total weight. Estimates of yaw, pitch, and roll inertias will be estimated or obtained from previous inertial measurements of the same vehicle. Likewise, center of gravity height will also be estimated, if not available from previous measurements. Measurements of wheelbase, wheel track, suspension locations, and overall geometry will also be performed.

Task C -- Tire Force Measurements

One tire from the test vehicle will be tested on the UMTRI flat-bed tire test machine to obtain lateral tire force measurements at three different loads (test load, 50% test load, 150% test load) and six slip angles (-1, 0, +1, 2, 4, 8 degrees). Tire cornering stiffness parameters needed by the driver model in subsequent model/test validation activities, as well as complete lateral tire force representation within the DADS model, will be based upon these measurements.

Task D -- Full Scale Vehicle Tests

Three sets of driver/vehicle maneuvers are planned for the test program. (1) The first test maneuver is simple steady turning by a driver along a circular path . The purpose of this test is to obtain estimates of the vehicle understeer and basic cornering properties, as well as, driver closed-loop steering control behavior into and during the steady turning maneuver. (2) The second maneuver is similar to the first, but braking will be applied during the turning maneuver by the driver so as to bring the vehicle to a stop at selected points along the curve. (3) Lastly, the third type of maneuver will be to drive through a set of different obstacle courses, as defined by a pattern of traffic cones.

All of the tests will be conducted at the Chrysler Proving Grounds at Chelsea, Michigan. The circular turning and braking-in-a-turn tests are planned for the skid pad area of the vehicle dynamics facility; the obstacle course runs will be performed along the straights (2-lane widths) of the facilities' oval track.

- **Driver-Controlled Constant Radius Turning Tests**

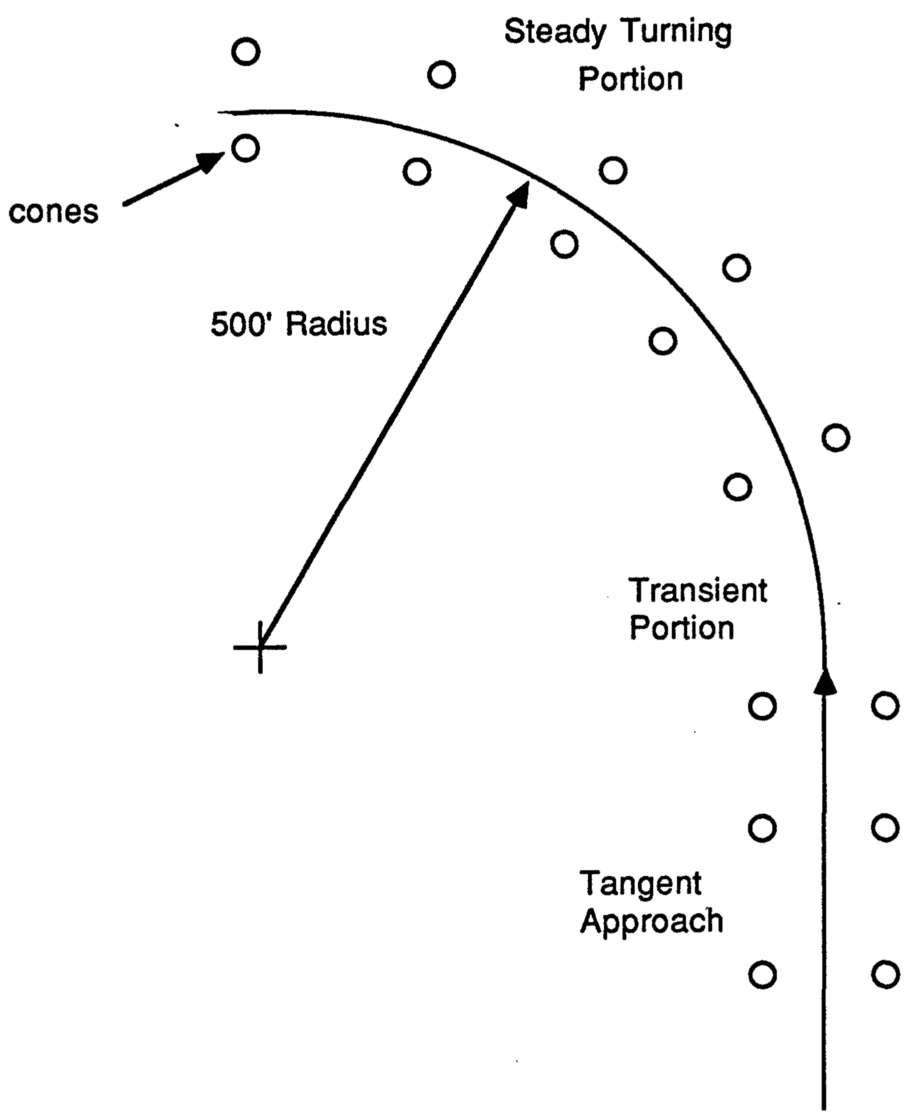
The turning tests will be conducted at 25 and 50 mph with the test driver attempting to track a cone-marked turn of fixed radius (500 '). (A radius of 500 feet will produce a lateral acceleration of 0.33 g's at 50 mph and can easily be accommodated on the 800' x 800' Chrysler skid pad area.) The maneuver will begin by having the driver approach the circular turn along a straight tangent and, then, track the curve at constant speed. See Figure 1. Transient driver/vehicle response information due to entering the curve, as well as steady-state driver/vehicle response information due to tracking the curve, will be gathered from these tests. Influence of forward speed upon system damping will be obtained by conducting the same tests at the two different speeds.

Vehicle turning properties, such as understeer level and steering control gains, will also be derived from the steady turning data in these tests. Further, since both front wheel angles and steering wheel angle are being measured, the effective steering gear ratio and steering system compliance properties will be available from these tests. (An additional low speed test may be added to the 25 and 50 mph cases if the lateral tire force data measured under Task C proves to be significantly sensitive to load or slip angle in the 0.0 to 0.3 g operating range.)

- **Driver-Controlled Braking-in-a-Turn Tests**

The braking-in-a-turn tests will be conducted from an initial speed of 50 mph with the test driver attempting to stop the vehicle in a fixed distance. The stopping distances will be varied, thereby requiring the driver to achieve different deceleration levels during each stop. This type of test will serve as a closed-loop braking control task for the driver, while simultaneously, yield information on the basic braking performance / capabilities of the test vehicle. Wheel lock-up occurrences will be recorded for the shorter stopping distance cases. The driver treadle pressure responses and corresponding deceleration time histories will be used to evaluate and refine the closed-loop braking algorithm.

Figure 1. Driver Controlled Constant Radius Turning Test



- **Obstacle Course Tests**

The purpose of these tests is to gather transient driver/vehicle response data for both path-following and obstacle avoidance maneuvers. The basic type of maneuver consists of performing various lane-to-lane movements with the vehicle as it traverses a cone-marked course. Tests will be conducted at speeds of 25 and 50 mph. Three basic obstacle course patterns are planned and are shown in Figure 2:

A) Simple Path-Constrained Lane Change (Figure 2a)

B) Simple Unconstrained Lane Change (Figure 2b)

and,

C) Unconstrained Obstacle Course (Figure 2c)

The first two cases are included primarily to evaluate the influence of path constraints on driver steering control behavior. The lane width will be systematically varied to help detect changes in driver steering behavior as the lane width narrows. Most of the obstacle course tests, however, will take place with the layout shown in Figure 2c. In these tests, the distance between rectangular obstacles, and their respective sizes, will be varied.

In all cases, the lane change geometry (shoot-to-shoot forward travel distance, L; or L1 and L2) will be adjusted to produce approximately 0.30 g's of peak lateral acceleration during the 50 mph maneuvers. The same course geometry will be used for the 25 mph tests in order to evaluate the influence of forward speed upon driver preview and system damping. Nominal course layouts will be initially selected on the basis of computer simulation runs performed during April.

Each of the unconstrained obstacle course tests will be repeated at least five times, but in a random-like sequence. The test driver will continuosly drive the vehicle dynamics oval — encountering a different obstacle course layout each time around the track. Data collection will begin several sconds prior to, and end several seconds after, the obstacle course maneuver.

Figure 2a. Path-Constrained Lane Change Maneuver

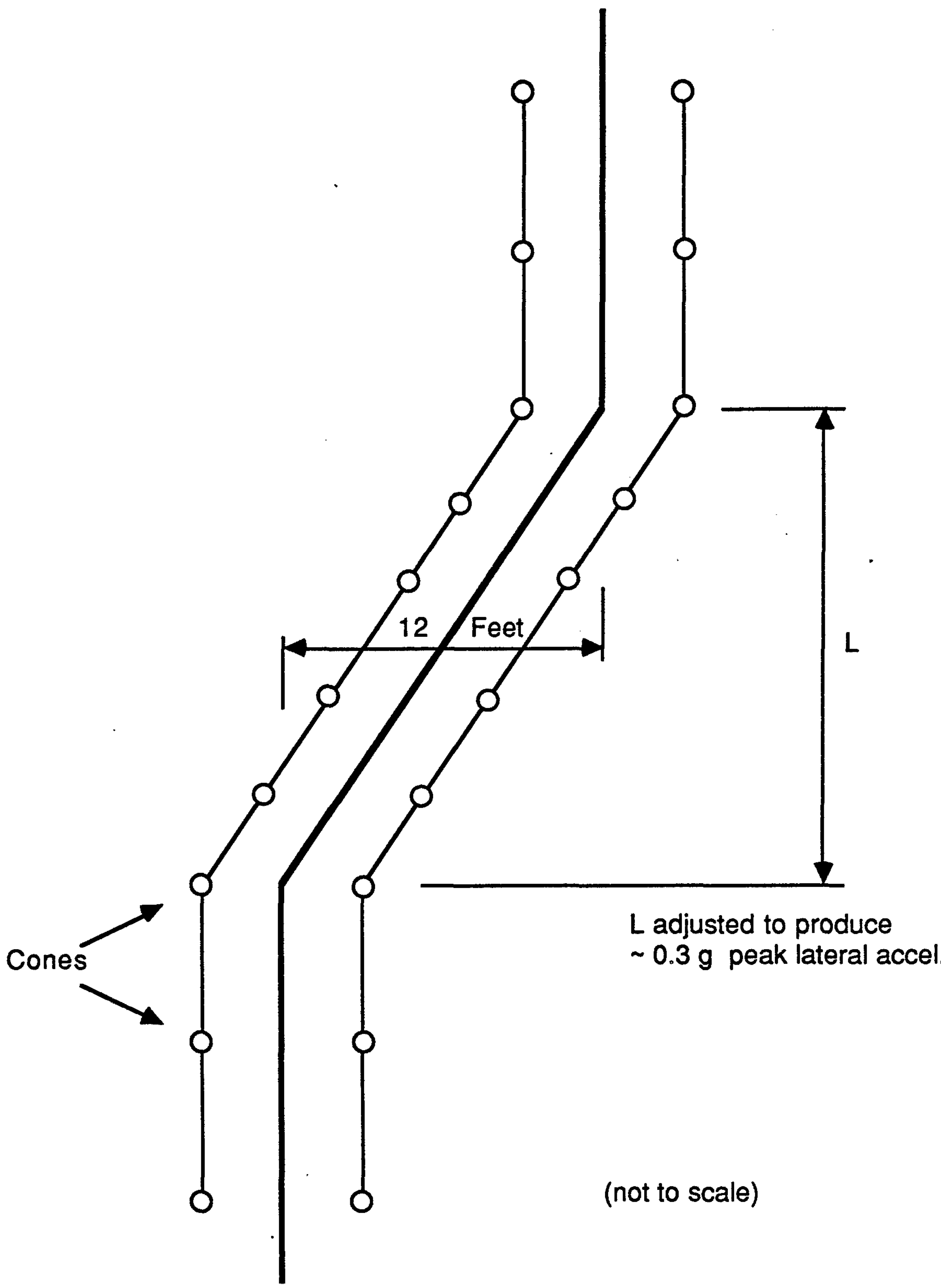


Figure 2b. Unconstrained Lane Change Maneuver

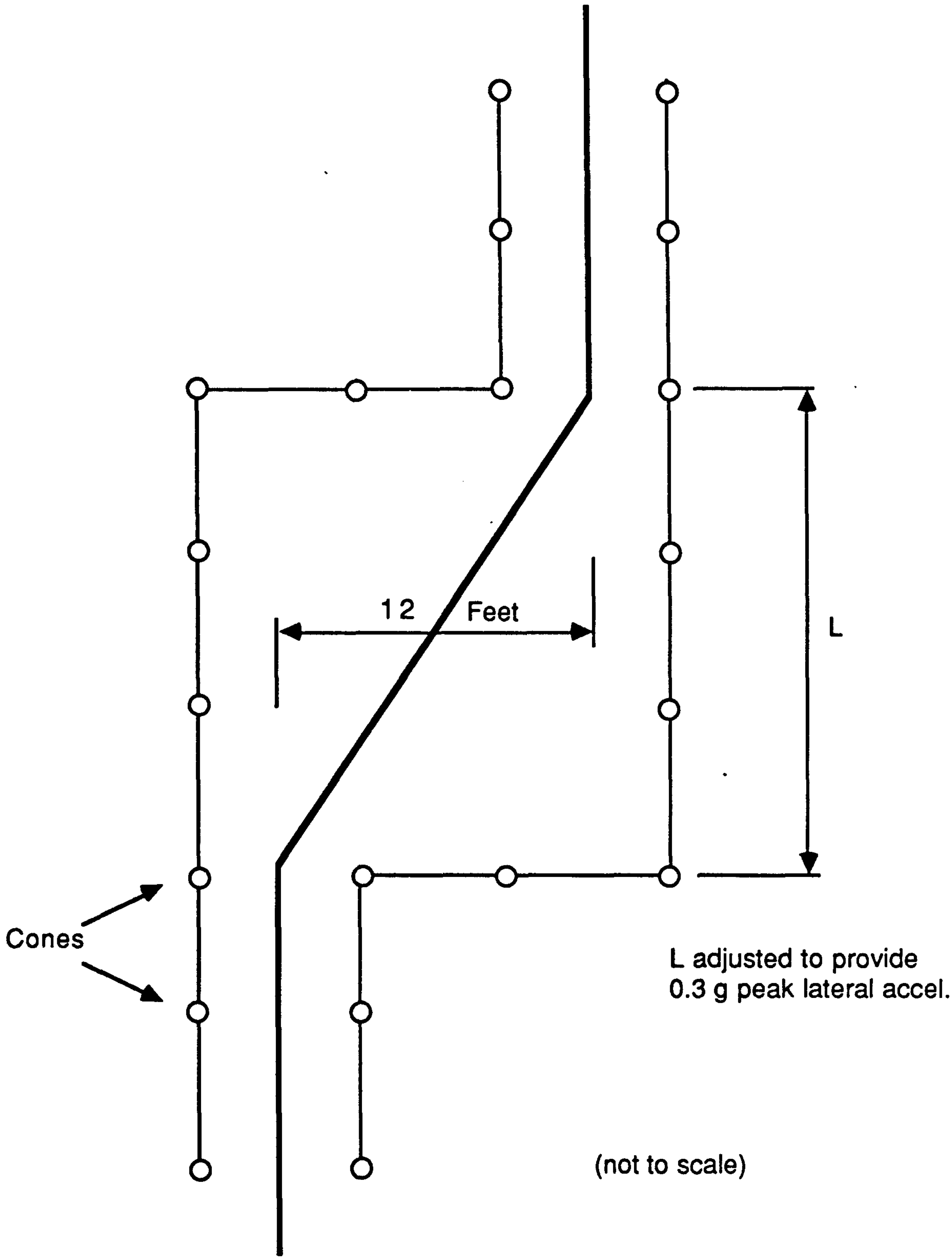
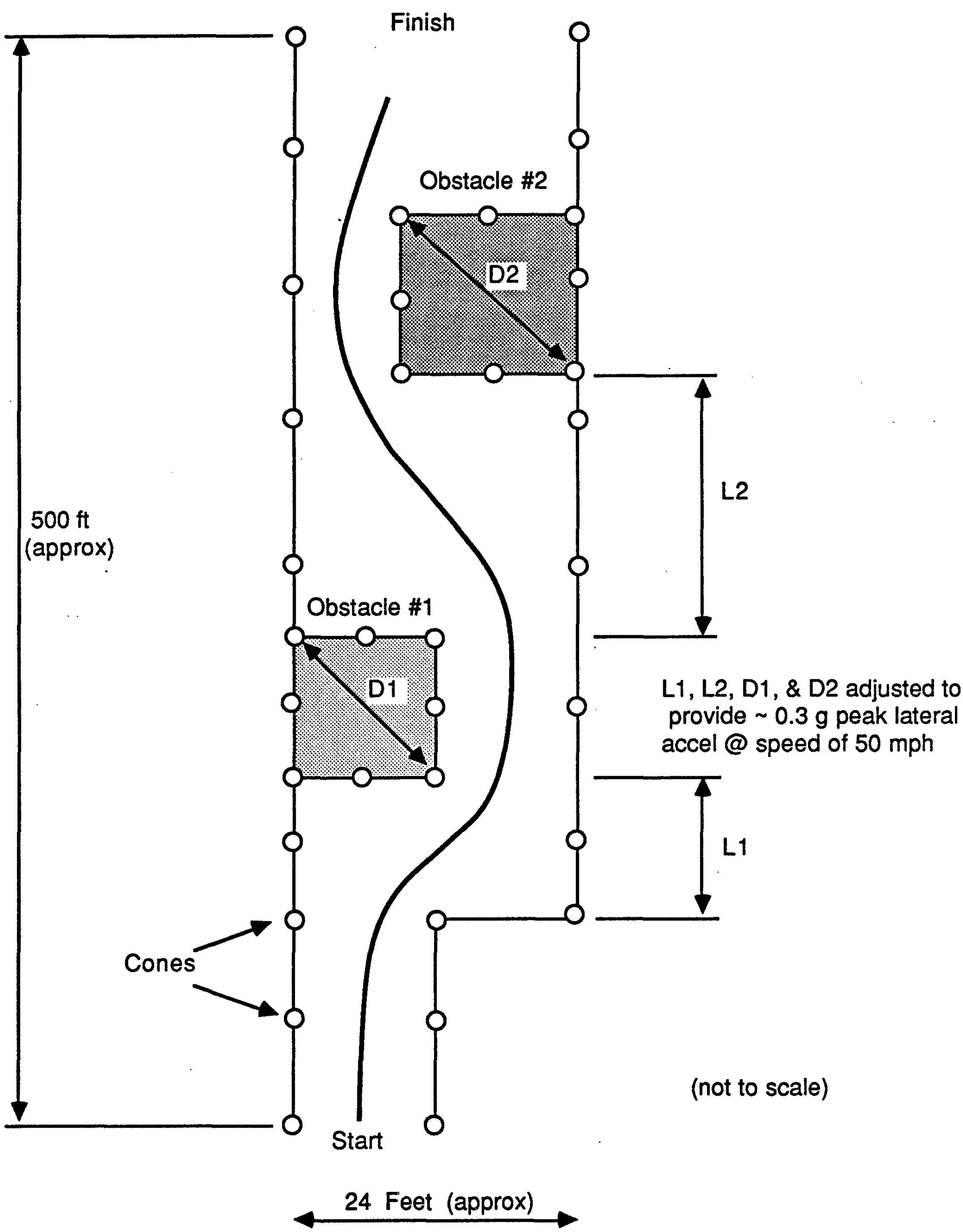


Figure 2c. Obstacle Course



- **Special HMMWV-Trailer Tests**

A short sequence of articulated vehicle tests will be conducted using a single-axle utility trailer attached to the HMMWV via its rear pintle-hook. The fore-aft location of the trailer load (in a low c.g. configuration) will be varied to produce different levels of damping in the trailer-swing motion. The resulting articulation angle response, and its possible effect upon driver steering control activity, will be evaluated during a repeat of several of the unconstrained obstacle course tests.

Straight-line stability tests may also be conducted with the trailer payload located in an adverse rearward location, thereby exciting a limit-cycle response in the articulation motion. The resulting driver steering action in response to the limit cycle motion will be useful in later analyzing and comparing with results from comparable simulation runs.

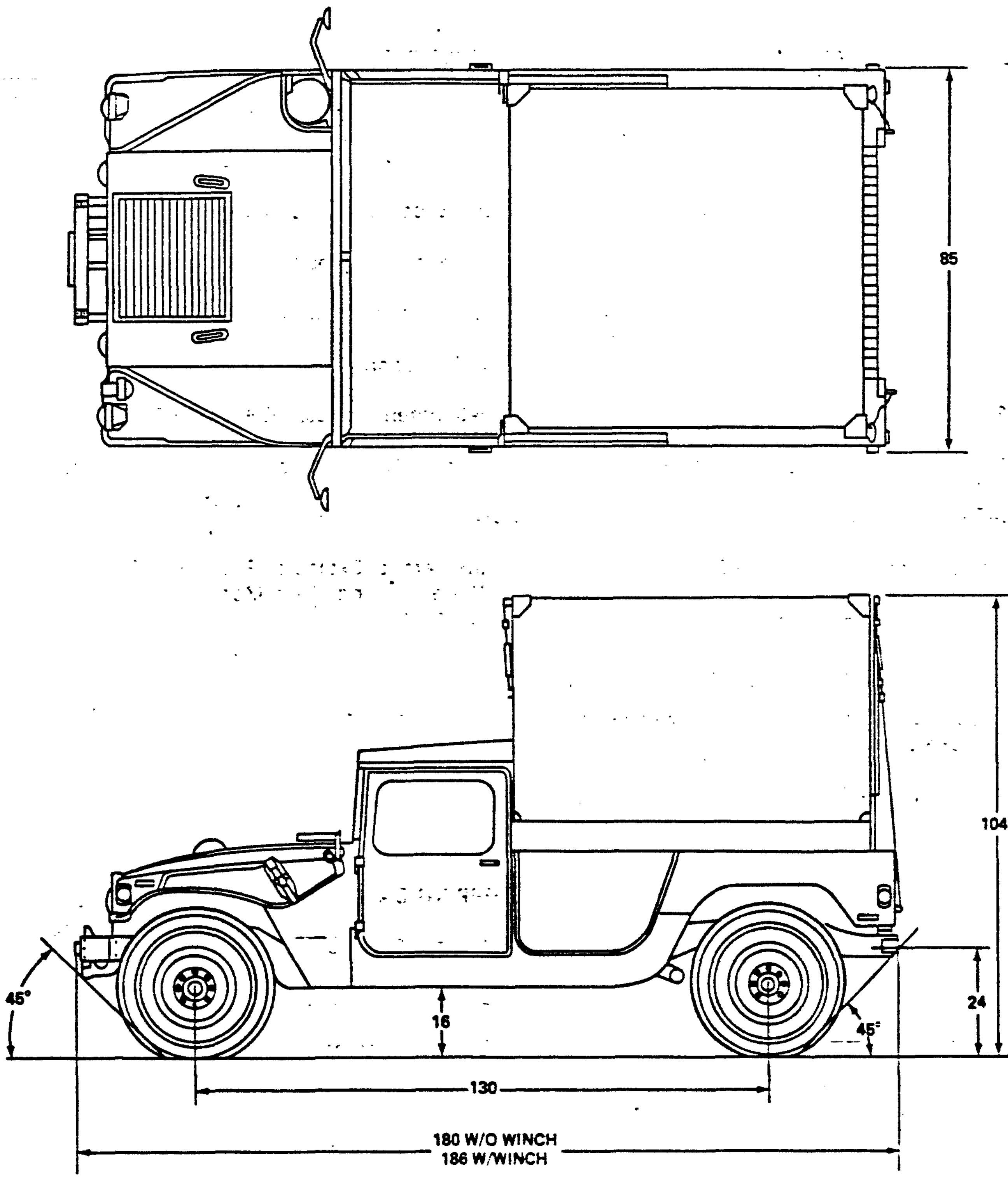
The trailer will be instrumented with four additional transducers to measure the following vehicle responses:

- Trailer Lateral Acceleration
- Trailer Yaw Rate
- HMMWV-Trailer Articulation Angle
- Trailer Roll Rate

Figures 3 and 4 show drawings of the HMMWV and utility trailer to be used in the test program.

43-0001-31

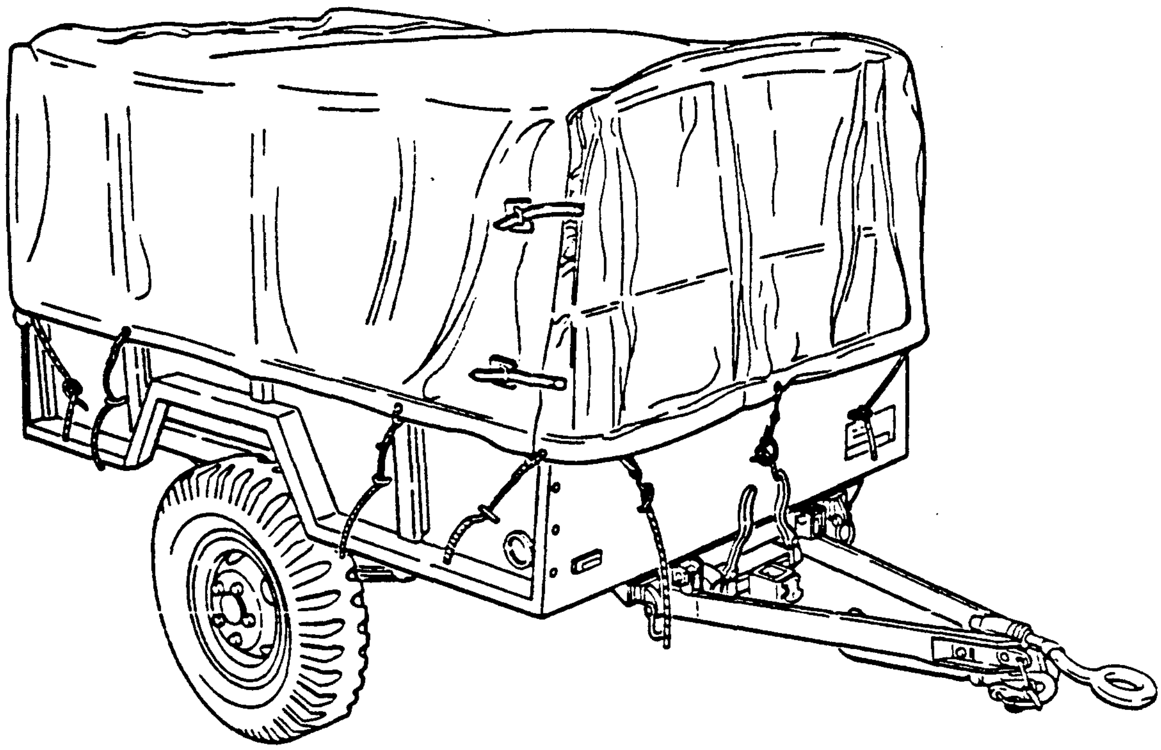
Figure 3. HMMWV Test Vehicle



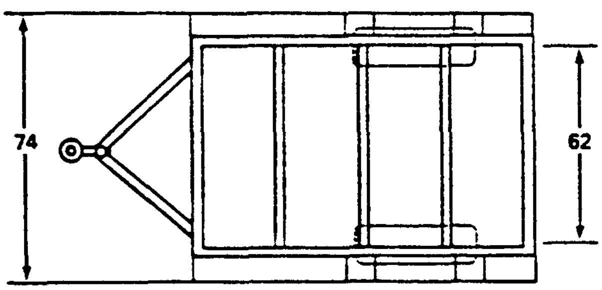
NOTE:
ALL DIMENSIONS ARE IN INCHES.

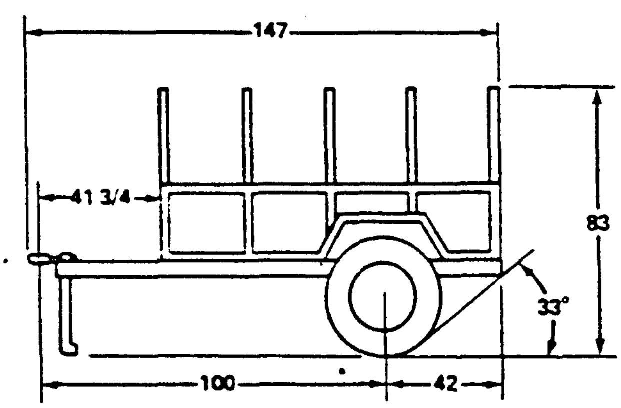
TA209188

Figure 4. Trailer Test Vehicle



NOTE:
ALL DIMENSIONS ARE IN INCHES.





TA208564

Data Acquisition Equipment

Test data will be collected using the UMTRI portable data acquisition system. The system consists of a Texas Instruments TM 990 microprocessor, signal-conditioning units, programmable filters, and analog/digital converters. A CRT unit and keyboard are used to operate and control the system. Data are stored on high capacity digital tape cartridges for subsequent post-processing. Simple statistical calculations and background calibrations can be performed as well.

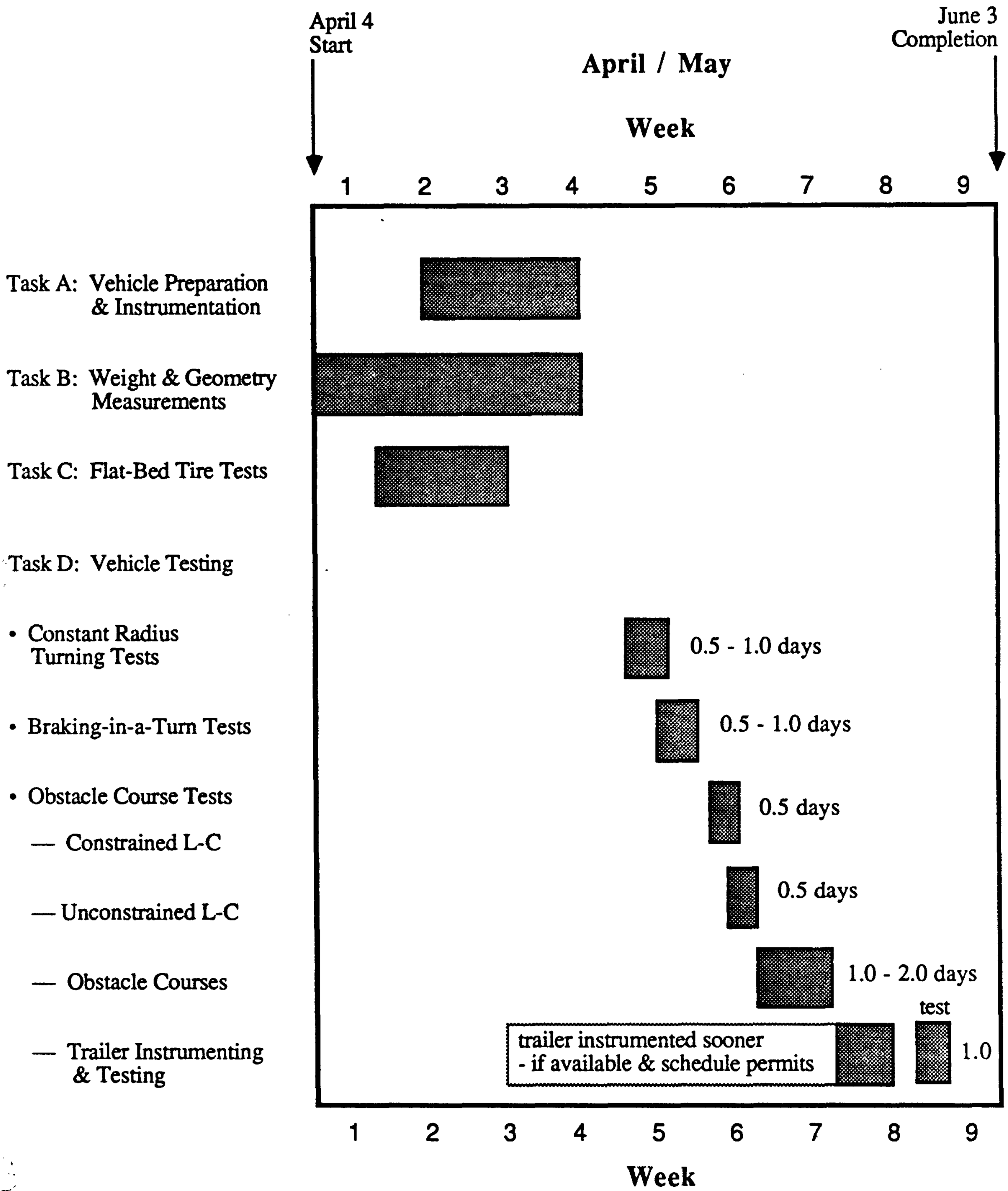
Spot checks of the collected data will occur periodically throughout the duration of the test program to guard against undetected instrumentation failures. However, most of the data processing for these tests will take place following the test program during June and July.

Test Schedule

Figure 5 shows the nominal schedule to be followed for completing the vehicle tests during April and May. Tasks A and B (vehicle preparation & instrumentation; weight & geometry measurements) will begin in April. Approximately 2-3 weeks of time are allotted to these tasks to allow for possible UMTRI staff technician commitments to other projects. Task C (flat-bed tire tests) is scheduled as well during this same time frame. An additional week is provided to account for possible staff conflicts and any unexpected problems. Finally, Task D (vehicle testing) is allocated one month of time during May, allowing for weather interruptions and instrumentation breakdowns.

As of this date, approximately two days per week (8 days) of track testing has been tentatively reserved with the Chrysler Proving Grounds for the month of May. It is expected that the skid pad testing can be completed during the first week of the test track schedule. The next week or two will be spent on the obstacle course testing. Depending upon the readiness of the trailer at this point, it will be instrumented (if not previously) and tested during the final week of scheduled tests.

Figure 5. TACOM Test Schedule / Spring 1988



APPENDIX B

Vehicle Data Files

```
CREATE HEADER
*
1. This a model of the high C.G. HMMWV M1037 S-250 Shelter Carrier vehicle
with bias tires and the M101 3160 lbf GVW trailer with radial tires.
*
2. See the user written subroutine USER_TSDA.FOR for the shock model.  The
subroutine will provide additional comments in more detail.
*
3. The umtri driver model implemented to steer the vehicle.  The file
DMINPUT.INP contains the parameters for the model.  The programs
LANE_CHANGE.EXE and CIRCLE generate the input file for the driver model.
Right now the model is used just to steer the vehicle down a given trajectory.
The parameters for the driver model my not be the precise required values.
*
4. The trailer hitch load is set at about 176 lbf which is about 6.3% of the
trailer spring weight.
*
5. This model is the 3rd config, i.e. the trailer cenetr of gravity
height of the trailer is 41.1 inches above the ground.
*
7. The front tires are bias type at 20 psi
The rear tires are bias type at 30 psi
There is no lateral force and aligning torque data at 30 psi so the data
for 28 psi was used as an approximation.
*
8. Assume the center of gravity of each wheel is at the wheel center.
The angle of 0.247 degrees associated with each wheel represents
the toe-in of the front wheels and the toe-out of the rear wheels.
See the HMMWV Technical Manual TM 9-2320-280-20, sections 8-6 and 8-7.
*

ANALYSIS
CREATE SYSTEM.DATA
   UNITS                          := 'ENG'
   ANALYSIS.TYPE                  := 'DYNAMIC'
   STARTING.TIME                  := '0.0'
   ENDING.TIME                    := '25.0'
   PRINT.INTERVAL                 := '0.06'
   GRAVITY.SEA.LEVEL              := '386.400'
   X.GRAVITY                      := '0.0'
   Y.GRAVITY                      := '0.0'
   Z.GRAVITY                      := '-1.0'
   SCALE.GRAVITY.COEF             := '1.0'
   MATRIX.OPERATIONS              := 'SPARSE'
   REDUNDANCY.CHECK               := 'TRUE'
   LU.TOL                         := '1.0D-12'
   ASSEMBLY.TOL                   := '1.0D-3'
   BYPASS.ASSEMBLY                := 'FALSE'
   OUTPUT.FILE                    := 'BINARY'
   REFERENCE.FRAME                := 'GLOBAL'
   DEBUG.FLAG                     := 'TRUE'
UP
CREATE DYNAMIC.DATA
   REACTION.FORCES                := 'TRUE'
   FORCE.COORDINATES              := 'GLOBAL'
   PRINT.METHOD                   := 'INTERPOLATED'
   MAX.INT.STEP                   := '0.05'
   SOLUTION.TOL                   := '0.001'
   INTEGRATION.TOL                := '0.0001'
UP
```

```
UP
CONSTRAINTS
CREATE DISTANCE.CONSTRAINT
    NAME                          := 'RAD-ROD.RL'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'WHEEL.RL'
    P.ON.BODY.1                   := ( -16.380, -161.980, 33.080 )
    P.ON.BODY.2                   := ( -32.327, -164.066, 30.405 )
    Q.ON.BODY.1                   := ( -16.380, -161.980, 34.080 )
    Q.ON.BODY.2                   := ( -32.327, -164.066, 31.405 )
    R.ON.BODY.1                   := ( -15.380, -161.980, 33.080 )
    R.ON.BODY.2                   := ( -31.327, -164.066, 30.405 )
    DISTANCE                      := '16.303798023773'
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE DISTANCE.CONSTRAINT
    NAME                          := 'RAD-ROD.RR'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'WHEEL.RR'
    P.ON.BODY.1                   := ( 16.380, -161.980, 33.080 )
    P.ON.BODY.2                   := ( 32.327, -164.066, 30.405 )
    Q.ON.BODY.1                   := ( 16.380, -161.980, 34.080 )
    Q.ON.BODY.2                   := ( 32.327, -164.066, 31.405 )
    R.ON.BODY.1                   := ( 17.380, -161.980, 33.080 )
    R.ON.BODY.2                   := ( 33.327, -164.066, 30.405 )
    DISTANCE                      := '16.303798023773'
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
UP
FORCE
CREATE RSDA
    NAME                          := 'TRAILER.AUX.ROLL.STIFFNESS'
    JOINT.NAME                    := 'TRAILER.REV'
    ORIENTATION.ANGLE             := '0.0'
    SPRING.CONSTANT               := '73153.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.TORQUE               := '0.0'
    CURVE.SPRING                  := 'NONE'
    CURVE.DAMPER                  := 'NONE'
    CURVE.ACTUATOR                := 'NONE'
    ANGULAR.UNITS                 := 'RADIANS'
UP
CREATE TIRE
    NAME                          := 'TIRE.FL'
    TIRE.BODY                     := 'WHEEL.FL'
    CHASSIS.BODY                  := 'CHASSIS'
    TYPE                          := 'BASIC'
    P.ON.TIRE                     := ( -35.815, -39.370, 29.735 )
    RADIUS                        := '18.150'
    ROLLING.RESISTANCE            := '0.0'
    DAMPING.CONSTANT              := '20.000'
    VERTICAL.STIFF                := '0.0'
    LATERAL.STIFF                 := '0.0'
    STEER.ANGLE                   := '0.0'
    FRICTION.COEFF                := '0.8'
    CURVE.UTILITY                 := 'TIRE.COEF'
    CURVE.VERTICAL                := 'BIAS.TIRE.20PSI'
    CURVE.TORQUE                  := 'NONE'
```

```
   CURVE.STEER                    := 'TRAJECTORY'
   ANGULAR.UNITS                  := 'DEGREES'
UP
CREATE TIRE
   NAME                           := 'TIRE.FR'
   TIRE.BODY                      := 'WHEEL.FR'
   CHASSIS.BODY                   := 'CHASSIS'
   TYPE                           := 'BASIC'
   P.ON.TIRE                      := ( 35.815, -39.370, 29.735 )
   RADIUS                         := '18.150'
   ROLLING.RESISTANCE             := '0.0'
   DAMPING.CONSTANT               := '20.000'
   VERTICAL.STIFF                 := '0.0'
   LATERAL.STIFF                  := '0.0'
   STEER.ANGLE                    := '0.0'
   FRICTION.COEFF                 := '0.8'
   CURVE.UTILITY                  := 'TIRE.COEF'
   CURVE.VERTICAL                 := 'BIAS.TIRE.20PSI'
   CURVE.TORQUE                   := 'NONE'
   CURVE.STEER                    := 'NONE'
   ANGULAR.UNITS                  := 'DEGREES'
UP
CREATE TIRE
   NAME                           := 'TIRE.RL'
   TIRE.BODY                      := 'WHEEL.RL'
   CHASSIS.BODY                   := 'CHASSIS'
   TYPE                           := 'BASIC'
   P.ON.TIRE                      := ( -35.815, -169.370, 29.735 )
   RADIUS                         := '18.150'
   ROLLING.RESISTANCE             := '0.0'
   DAMPING.CONSTANT               := '20.000'
   VERTICAL.STIFF                 := '0.0'
   LATERAL.STIFF                  := '0.0'
   STEER.ANGLE                    := '0.0'
   FRICTION.COEFF                 := '0.8'
   CURVE.UTILITY                  := 'TIRE.COEF'
   CURVE.VERTICAL                 := 'BIAS.TIRE.30PSI'
   CURVE.TORQUE                   := 'NONE'
   CURVE.STEER                    := 'NONE'
   ANGULAR.UNITS                  := 'DEGREES'
UP
CREATE TIRE
   NAME                           := 'TIRE.RR'
   TIRE.BODY                      := 'WHEEL.RR'
   CHASSIS.BODY                   := 'CHASSIS'
   TYPE                           := 'BASIC'
   P.ON.TIRE                      := ( 35.815, -169.370, 29.735 )
   RADIUS                         := '18.150'
   ROLLING.RESISTANCE             := '0.0'
   DAMPING.CONSTANT               := '20.000'
   VERTICAL.STIFF                 := '0.0'
   LATERAL.STIFF                  := '0.0'
   STEER.ANGLE                    := '0.0'
   FRICTION.COEFF                 := '0.8'
   CURVE.UTILITY                  := 'TIRE.COEF'
   CURVE.VERTICAL                 := 'BIAS.TIRE.30PSI'
   CURVE.TORQUE                   := 'NONE'
   CURVE.STEER                    := 'NONE'
   ANGULAR.UNITS                  := 'DEGREES'
UP
```

```
CREATE TIRE
   NAME                          := 'TRAILER.TIRE.RH'
   TIRE.BODY                     := 'TRAILER.AXLE'
   CHASSIS.BODY                  := 'TRAILER.CHASSIS'
   TYPE                          := 'BASIC'
   P.ON.TIRE                     := ( 31.0, -305.37, 27.88 )
   RADIUS                        := '16.0'
   ROLLING.RESISTANCE            := '0.0'
   DAMPING.CONSTANT              := '0.000'
   VERTICAL.STIFF                := '0.0'
   LATERAL.STIFF                 := '0.0'
   STEER.ANGLE                   := '0.0'
   FRICTION.COEFF                := '0.8'
   CURVE.UTILITY                 := 'TIRE.COEF'
   CURVE.VERTICAL                := 'RADIAL.TIRE.LT235.85R16'
   CURVE.TORQUE                  := 'NONE'
   CURVE.STEER                   := 'NONE'
   ANGULAR.UNITS                 := 'DEGREES'
UP
CREATE TIRE
   NAME                          := 'TRAILER.TIRE.LH'
   TIRE.BODY                     := 'TRAILER.AXLE'
   CHASSIS.BODY                  := 'TRAILER.CHASSIS'
   TYPE                          := 'BASIC'
   P.ON.TIRE                     := ( -31.0, -305.37, 27.88 )
   RADIUS                        := '16.0'
   ROLLING.RESISTANCE            := '0.0'
   DAMPING.CONSTANT              := '0.000'
   VERTICAL.STIFF                := '0.0'
   LATERAL.STIFF                 := '0.0'
   STEER.ANGLE                   := '0.0'
   FRICTION.COEFF                := '0.8'
   CURVE.UTILITY                 := 'TIRE.COEF'
   CURVE.VERTICAL                := 'RADIAL.TIRE.LT235.85R16'
   CURVE.TORQUE                  := 'NONE'
   CURVE.STEER                   := 'NONE'
   ANGULAR.UNITS                 := 'DEGREES'
UP
CREATE TSDA
   NAME                          := 'SPRING.FL'
   BODY.1.NAME                   := 'CHASSIS'
   BODY.2.NAME                   := 'ARM.LFL'
   SPRING.CONSTANT               := '954.000'
   FREE.LENGTH.SPRING            := '13.360'
   DAMPING.COEFFICIENT           := '0.0'
   ACTUATOR.FORCE                := '0.0'
   P.ON.BODY.1                   := ( -20.070, -33.685, 38.545 )
   P.ON.BODY.2                   := ( -21.385, -33.953, 28.935 )
   Q.ON.BODY.1                   := ( -20.070, -33.685, 39.545 )
   Q.ON.BODY.2                   := ( -21.385, -33.953, 29.935 )
   R.ON.BODY.1                   := ( -19.070, -33.685, 38.545 )
   R.ON.BODY.2                   := ( -20.385, -33.953, 28.935 )
   CURVE.SPRING                  := 'NONE'
   CURVE.DAMPER                  := 'NONE'
   CURVE.ACTUATOR                := 'NONE'
   NODE.1                        := '0'
   NODE.2                        := '0'
UP
CREATE TSDA
   NAME                          := 'SPRING.FR'
```

```
   BODY.1.NAME                          := 'CHASSIS'
   BODY.2.NAME                          := 'ARM.LFR'
   SPRING.CONSTANT                      := '954.000'
   FREE.LENGTH.SPRING                   := '13.360'
   DAMPING.COEFFICIENT                  := '0.0'
   ACTUATOR.FORCE                       := '0.0'
   P.ON.BODY.1                          := ( 20.070, -33.685, 38.545 )
   P.ON.BODY.2                          := ( 21.385, -33.953, 28.935 )
   Q.ON.BODY.1                          := ( 20.070, -33.685, 39.545 )
   Q.ON.BODY.2                          := ( 21.385, -33.953, 29.935 )
   R.ON.BODY.1                          := ( 21.070, -33.685, 38.545 )
   R.ON.BODY.2                          := ( 22.385, -33.953, 28.935 )
   CURVE.SPRING                         := 'NONE'
   CURVE.DAMPER                         := 'NONE'
   CURVE.ACTUATOR                       := 'NONE'
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE TSDA
   NAME                                 := 'SPRING.RL'
   BODY.1.NAME                          := 'CHASSIS'
   BODY.2.NAME                          := 'ARM.LRL'
   SPRING.CONSTANT                      := '2108.000'
   FREE.LENGTH.SPRING                   := '15.030'
   DAMPING.COEFFICIENT                  := '0.0'
   ACTUATOR.FORCE                       := '0.0'
   P.ON.BODY.1                          := ( -19.747, -174.865, 40.868 )
   P.ON.BODY.2                          := ( -21.385, -174.597, 28.935 )
   Q.ON.BODY.1                          := ( -19.747, -174.865, 41.868 )
   Q.ON.BODY.2                          := ( -21.385, -174.597, 29.935 )
   R.ON.BODY.1                          := ( -18.747, -174.865, 40.868 )
   R.ON.BODY.2                          := ( -20.385, -174.597, 28.935 )
   CURVE.SPRING                         := 'NONE'
   CURVE.DAMPER                         := 'NONE'
   CURVE.ACTUATOR                       := 'NONE'
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE TSDA
   NAME                                 := 'SPRING.RR'
   BODY.1.NAME                          := 'CHASSIS'
   BODY.2.NAME                          := 'ARM.LRR'
   SPRING.CONSTANT                      := '2108.00'
   FREE.LENGTH.SPRING                   := '15.030'
   DAMPING.COEFFICIENT                  := '0.0'
   ACTUATOR.FORCE                       := '0.0'
   P.ON.BODY.1                          := ( 19.747, -174.865, 40.868 )
   P.ON.BODY.2                          := ( 21.385, -174.597, 28.935 )
   Q.ON.BODY.1                          := ( 19.747, -174.865, 41.868 )
   Q.ON.BODY.2                          := ( 21.385, -174.597, 29.935 )
   R.ON.BODY.1                          := ( 20.747, -174.865, 40.868 )
   R.ON.BODY.2                          := ( 22.385, -174.597, 28.935 )
   CURVE.SPRING                         := 'NONE'
   CURVE.DAMPER                         := 'NONE'
   CURVE.ACTUATOR                       := 'NONE'
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE TSDA
   NAME                                 := 'SHOCK.FL'
```

```
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LFL'
    SPRING.CONSTANT                      := '0.0'
    FREE.LENGTH.SPRING                   := '0.0'
    DAMPING.COEFFICIENT                  := '0.0'
    ACTUATOR.FORCE                       := '0.0'
    P.ON.BODY.1                          := ( -19.598, -33.685, 43.492 )
    P.ON.BODY.2                          := ( -21.415, -33.953, 29.259 )
    Q.ON.BODY.1                          := ( -19.598, -33.685, 44.492 )
    Q.ON.BODY.2                          := ( -21.415, -33.953, 30.259 )
    R.ON.BODY.1                          := ( -18.598, -33.685, 43.492 )
    R.ON.BODY.2                          := ( -20.415, -33.953, 29.259 )
    CURVE.SPRING                         := 'NONE'
    CURVE.DAMPER                         := 'NONE'
    CURVE.ACTUATOR                       := 'NONE'
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE TSDA
    NAME                                 := 'SHOCK.FR'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LFR'
    SPRING.CONSTANT                      := '0.0'
    FREE.LENGTH.SPRING                   := '0.0'
    DAMPING.COEFFICIENT                  := '0.0'
    ACTUATOR.FORCE                       := '0.0'
    P.ON.BODY.1                          := ( 19.598, -33.685, 43.492 )
    P.ON.BODY.2                          := ( 21.415, -33.953, 29.259 )
    Q.ON.BODY.1                          := ( 19.598, -33.685, 44.492 )
    Q.ON.BODY.2                          := ( 21.415, -33.953, 30.259 )
    R.ON.BODY.1                          := ( 20.598, -33.685, 43.492 )
    R.ON.BODY.2                          := ( 22.415, -33.953, 29.259 )
    CURVE.SPRING                         := 'NONE'
    CURVE.DAMPER                         := 'NONE'
    CURVE.ACTUATOR                       := 'NONE'
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE TSDA
    NAME                                 := 'SHOCK.RL'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LRL'
    SPRING.CONSTANT                      := '0.0'
    FREE.LENGTH.SPRING                   := '0.0'
    DAMPING.COEFFICIENT                  := '0.0'
    ACTUATOR.FORCE                       := '0.0'
    P.ON.BODY.1                          := ( -19.598, -174.865, 43.492 )
    P.ON.BODY.2                          := ( -21.415, -174.597, 29.259 )
    Q.ON.BODY.1                          := ( -19.598, -174.865, 44.492 )
    Q.ON.BODY.2                          := ( -21.415, -174.597, 30.259 )
    R.ON.BODY.1                          := ( -18.598, -174.865, 43.492 )
    R.ON.BODY.2                          := ( -20.415, -174.597, 29.259 )
    CURVE.SPRING                         := 'NONE'
    CURVE.DAMPER                         := 'NONE'
    CURVE.ACTUATOR                       := 'NONE'
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE TSDA
    NAME                                 := 'SHOCK.RR'
```

```
      BODY.1.NAME                      := 'CHASSIS'
      BODY.2.NAME                      := 'ARM.LRR'
      SPRING.CONSTANT                  := '0.0'
      FREE.LENGTH.SPRING               := '0.0'
      DAMPING.COEFFICIENT              := '0.0'
      ACTUATOR.FORCE                   := '0.0'
      P.ON.BODY.1                      := ( 19.598, -174.865, 43.492 )
      P.ON.BODY.2                      := ( 21.415, -174.597, 29.259 )
      Q.ON.BODY.1                      := ( 19.598, -174.865, 44.492 )
      Q.ON.BODY.2                      := ( 21.415, -174.597, 30.259 )
      R.ON.BODY.1                      := ( 20.598, -174.865, 43.492 )
      R.ON.BODY.2                      := ( 22.415, -174.597, 29.259 )
      CURVE.SPRING                     := 'NONE'
      CURVE.DAMPER                     := 'NONE'
      CURVE.ACTUATOR                   := 'NONE'
      NODE.1                           := '0'
      NODE.2                           := '0'
   UP
   CREATE TSDA
      NAME                             := 'TIEROD.FL'
      BODY.1.NAME                      := 'STEERING.LINK'
      BODY.2.NAME                      := 'WHEEL.FL'
      SPRING.CONSTANT                  := '4280.0'
      FREE.LENGTH.SPRING               := '15.2179994513076'
      DAMPING.COEFFICIENT              := '11.0'
      ACTUATOR.FORCE                   := '0.0'
      P.ON.BODY.1                      := ( -17.65, -47.635, 32.905 )
      P.ON.BODY.2                      := ( -32.327, -44.702, 30.127 )
      Q.ON.BODY.1                      := ( -17.65, -47.635, 33.905 )
      Q.ON.BODY.2                      := ( -32.327, -44.702, 31.127 )
      R.ON.BODY.1                      := ( -16.65, -47.635, 32.905 )
      R.ON.BODY.2                      := ( -31.327, -44.702, 30.127 )
      CURVE.SPRING                     := 'NONE'
      CURVE.DAMPER                     := 'NONE'
      CURVE.ACTUATOR                   := 'NONE'
      NODE.1                           := '0'
      NODE.2                           := '0'
   UP
   CREATE TSDA
      NAME                             := 'TIEROD.FR'
      BODY.1.NAME                      := 'STEERING.LINK'
      BODY.2.NAME                      := 'WHEEL.FR'
      SPRING.CONSTANT                  := '4280.0'
      FREE.LENGTH.SPRING               := '15.217994513076'
      DAMPING.COEFFICIENT              := '11.0'
      ACTUATOR.FORCE                   := '0.0'
      P.ON.BODY.1                      := ( 17.655, -47.635, 32.905 )
      P.ON.BODY.2                      := ( 32.327, -44.702, 30.127 )
      Q.ON.BODY.1                      := ( 17.655, -47.635, 33.905 )
      Q.ON.BODY.2                      := ( 32.327, -44.702, 31.127 )
      R.ON.BODY.1                      := ( 18.655, -47.635, 32.905 )
      R.ON.BODY.2                      := ( 33.327, -44.702, 30.127 )
      CURVE.SPRING                     := 'NONE'
      CURVE.DAMPER                     := 'NONE'
      CURVE.ACTUATOR                   := 'NONE'
      NODE.1                           := '0'
      NODE.2                           := '0'
   UP
   CREATE TSDA
      NAME                             := 'TRAILER.SPRING.LH'
```

```
    BODY.1.NAME                       := 'TRAILER.AXLE'
    BODY.2.NAME                       := 'TRAILER.CHASSIS'
    SPRING.CONSTANT                   := '0.0'
    FREE.LENGTH.SPRING                := '18.2'
    DAMPING.COEFFICIENT               := '0.0'
    ACTUATOR.FORCE                    := '0.0'
    P.ON.BODY.1                       := ( -21.25, -305.37, 27.38 )
    P.ON.BODY.2                       := ( -21.25, -305.37, 43.38 )
    Q.ON.BODY.1                       := ( -21.25, -305.37, 28.38 )
    Q.ON.BODY.2                       := ( -21.25, -305.37, 44.38 )
    R.ON.BODY.1                       := ( -20.25, -305.37, 27.38 )
    R.ON.BODY.2                       := ( -20.25, -305.37, 43.38 )
    CURVE.SPRING                      := 'TRAILER.SPRING.CURVE'
    CURVE.DAMPER                      := 'TRAILER.SPRING.FRICT'
    CURVE.ACTUATOR                    := 'NONE'
    NODE.1                            := '0'
    NODE.2                            := '0'
UP
CREATE TSDA
    NAME                              := 'TRAILER.SPRING.RH'
    BODY.1.NAME                       := 'TRAILER.AXLE'
    BODY.2.NAME                       := 'TRAILER.CHASSIS'
    SPRING.CONSTANT                   := '0.0'
    FREE.LENGTH.SPRING                := '18.2'
    DAMPING.COEFFICIENT               := '0.0'
    ACTUATOR.FORCE                    := '0.0'
    P.ON.BODY.1                       := ( 21.25, 305.37, 27.38 )
    P.ON.BODY.2                       := ( 21.25, 305.37, 43.38 )
    Q.ON.BODY.1                       := ( 21.25, 305.37, 28.38 )
    Q.ON.BODY.2                       := ( 21.25, 305.37, 44.38 )
    R.ON.BODY.1                       := ( 22.25, 305.37, 27.38 )
    R.ON.BODY.2                       := ( 22.25, 305.37, 43.38 )
    CURVE.SPRING                      := 'TRAILER.SPRING.CURVE'
    CURVE.DAMPER                      := 'TRAILER.SPRING.FRICT'
    CURVE.ACTUATOR                    := 'NONE'
    NODE.1                            := '0'
    NODE.2                            := '0'
UP
CREATE TSDA
    NAME                              := 'TRAILER.SHOCK.LH'
    BODY.1.NAME                       := 'TRAILER.CHASSIS'
    BODY.2.NAME                       := 'TRAILER.AXLE'
    SPRING.CONSTANT                   := '0.0'
    FREE.LENGTH.SPRING                := '0.0'
    DAMPING.COEFFICIENT               := '0.0'
    ACTUATOR.FORCE                    := '0.0'
    P.ON.BODY.1                       := ( -9.85, -308.82, 37.88 )
    P.ON.BODY.2                       := ( -18.9, -308.82, 25.48 )
    Q.ON.BODY.1                       := ( -9.85, -308.82, 38.88 )
    Q.ON.BODY.2                       := ( -18.9, -308.82, 26.48 )
    R.ON.BODY.1                       := ( -8.85, -308.82, 37.88 )
    R.ON.BODY.2                       := ( -17.9, -308.82, 25.48 )
    CURVE.SPRING                      := 'NONE'
    CURVE.DAMPER                      := 'TRAILER.SHOCK.CURVE'
    CURVE.ACTUATOR                    := 'NONE'
    NODE.1                            := '0'
    NODE.2                            := '0'
UP
CREATE TSDA
    NAME                              := 'TRAILER.SHOCK.RH'
```

```
   BODY.1.NAME                            := 'TRAILER.CHASSIS'
   BODY.2.NAME                            := 'TRAILER.AXLE'
   SPRING.CONSTANT                        := '0.0'
   FREE.LENGTH.SPRING                     := '0.0'
   DAMPING.COEFFICIENT                    := '0.0'
   ACTUATOR.FORCE                         := '0.0'
   P.ON.BODY.1                            := ( 9.85, -308.82, 37.88 )
   P.ON.BODY.2                            := ( 18.9, -308.82, 25.48 )
   Q.ON.BODY.1                            := ( 9.85, -308.82, 38.88 )
   Q.ON.BODY.2                            := ( 18.9, -308.82, 26.48 )
   R.ON.BODY.1                            := ( 10.85, -308.82, 37.88 )
   R.ON.BODY.2                            := ( 19.9, -308.82, 25.48 )
   CURVE.SPRING                           := 'NONE'
   CURVE.DAMPER                           := 'TRAILER.SHOCK.CURVE'
   CURVE.ACTUATOR                         := 'NONE'
   NODE.1                                 := '0'
   NODE.2                                 := '0'
UP
UP
JOINTS
CREATE REVOLUTE.JOINT
   NAME                                   := 'REV.LFL'
   BODY.1.NAME                            := 'CHASSIS'
   BODY.2.NAME                            := 'ARM.LFL'
   P.ON.BODY.1                            := ( -12.09, -37.78, 30.770 )
   P.ON.BODY.2                            := ( -12.09, -37.78, 30.770 )
   Q.ON.BODY.1                            := ( -12.09, -36.78, 30.770 )
   Q.ON.BODY.2                            := ( -12.09, -36.78, 30.770 )
   R.ON.BODY.1                            := ( -11.09, -37.78, 30.770 )
   R.ON.BODY.2                            := ( -11.09, -37.78, 30.770 )
   NODE.1                                 := '0'
   NODE.2                                 := '0'
UP
CREATE REVOLUTE.JOINT
   NAME                                   := 'REV.LFR'
   BODY.1.NAME                            := 'CHASSIS'
   BODY.2.NAME                            := 'ARM.LFR'
   P.ON.BODY.1                            := ( 12.09, -37.78, 30.770 )
   P.ON.BODY.2                            := ( 12.09, -37.78, 30.770 )
   Q.ON.BODY.1                            := ( 12.09, -36.78, 30.770 )
   Q.ON.BODY.2                            := ( 12.09, -36.78, 30.770 )
   R.ON.BODY.1                            := ( 13.09, -37.78, 30.770 )
   R.ON.BODY.2                            := ( 13.09, -37.78, 30.770 )
   NODE.1                                 := '0'
   NODE.2                                 := '0'
UP
CREATE REVOLUTE.JOINT
   NAME                                   := 'REV.LRL'
   BODY.1.NAME                            := 'CHASSIS'
   BODY.2.NAME                            := 'ARM.LRL'
   P.ON.BODY.1                            := ( -12.09, -170.77, 30.770 )
   P.ON.BODY.2                            := ( -12.09, -170.77, 30.770 )
   Q.ON.BODY.1                            := ( -12.09, -169.77, 30.770 )
   Q.ON.BODY.2                            := ( -12.09, -169.77, 30.770 )
   R.ON.BODY.1                            := ( -11.09, -170.77, 30.770 )
   R.ON.BODY.2                            := ( -11.09, -170.77, 30.770 )
   NODE.1                                 := '0'
   NODE.2                                 := '0'
UP
CREATE REVOLUTE.JOINT
```

```
    NAME                          := 'REV.LRR'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LRR'
    P.ON.BODY.1                   := ( 12.09, -170.77, 30.770 )
    P.ON.BODY.2                   := ( 12.09, -170.77, 30.770 )
    Q.ON.BODY.1                   := ( 12.09, -169.77, 30.770 )
    Q.ON.BODY.2                   := ( 12.09, -169.77, 30.770 )
    R.ON.BODY.1                   := ( 13.09, -170.77, 30.770 )
    R.ON.BODY.2                   := ( 13.09, -170.77, 30.770 )
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                          := 'REV.UFL'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.UFL'
    P.ON.BODY.1                   := ( -18.183, -44.003, 39.435 )
    P.ON.BODY.2                   := ( -18.183, -44.003, 39.435 )
    Q.ON.BODY.1                   := ( -17.558, -39.670, 40.400 )
    Q.ON.BODY.2                   := ( -17.558, -39.670, 40.400 )
    R.ON.BODY.1                   := ( -17.193, -44.146, 39.435 )
    R.ON.BODY.2                   := ( -17.193, -44.146, 39.435 )
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                          := 'REV.UFR'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.UFR'
    P.ON.BODY.1                   := ( 18.183, -44.003, 39.435 )
    P.ON.BODY.2                   := ( 18.183, -44.003, 39.435 )
    Q.ON.BODY.1                   := ( 17.558, -39.670, 40.400 )
    Q.ON.BODY.2                   := ( 17.558, -39.670, 40.400 )
    R.ON.BODY.1                   := ( 19.173, -43.860, 39.435 )
    R.ON.BODY.2                   := ( 19.173, -43.860, 39.435 )
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                          := 'REV.URL'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.URL'
    P.ON.BODY.1                   := ( -18.195, -162.380, 39.655 )
    P.ON.BODY.2                   := ( -18.195, -162.380, 39.655 )
    Q.ON.BODY.1                   := ( -18.195, -161.380, 39.655 )
    Q.ON.BODY.2                   := ( -18.195, -161.380, 39.655 )
    R.ON.BODY.1                   := ( -17.195, -162.380, 39.655 )
    R.ON.BODY.2                   := ( -17.195, -162.380, 39.655 )
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                          := 'REV.URR'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.URR'
    P.ON.BODY.1                   := ( 18.195, -162.380, 39.655 )
    P.ON.BODY.2                   := ( 18.195, -162.380, 39.655 )
    Q.ON.BODY.1                   := ( 18.195, -161.380, 39.655 )
    Q.ON.BODY.2                   := ( 18.195, -161.380, 39.655 )
    R.ON.BODY.1                   := ( 19.195, -162.380, 39.655 )
```

```
   R.ON.BODY.2                          := ( 19.195, -162.380, 39.655 )
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
   NAME                                 := 'PITMAN.REV'
   BODY.1.NAME                          := 'CHASSIS'
   BODY.2.NAME                          := 'PITMAN.ARM'
   P.ON.BODY.1                          := ( -9.811, -55.355, 34.039 )
   P.ON.BODY.2                          := ( -9.811, -55.355, 34.039 )
   Q.ON.BODY.1                          := ( -9.811, -55.038, 34.987 )
   Q.ON.BODY.2                          := ( -9.811, -55.038, 34.987 )
   R.ON.BODY.1                          := ( -8.811, -55.355, 34.039 )
   R.ON.BODY.2                          := ( -8.811, -55.355, 34.039 )
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
   NAME                                 := 'TRAILER.REV'
   BODY.1.NAME                          := 'TRAILER.DUMMY'
   BODY.2.NAME                          := 'TRAILER.AXLE'
   P.ON.BODY.1                          := ( 0.0, -305.37, 32.88 )
   P.ON.BODY.2                          := ( 0.0, -305.37, 32.88 )
   Q.ON.BODY.1                          := ( 0.0, -304.37, 32.88 )
   Q.ON.BODY.2                          := ( 0.0, -304.37, 32.88 )
   R.ON.BODY.1                          := ( 1.0, -305.37, 32.88 )
   R.ON.BODY.2                          := ( 1.0, -305.37, 32.88 )
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE REV-SPHR.JOINT
   NAME                                 := 'IDLER.ARM'
   REV.BODY.1.NAME                      := 'CHASSIS'
   SPHR.BODY.2.NAME                     := 'STEERING.LINK'
   P.ON.BODY.1                          := ( 12.803, -55.355, 34.039 )
   P.ON.BODY.2                          := ( 12.803, -50.556, 32.433 )
   Q.ON.BODY.1                          := ( 12.803, -55.038, 34.987 )
   Q.ON.BODY.2                          := ( 12.803, -50.239, 33.381 )
   R.ON.BODY.1                          := ( 13.803, -55.355, 34.039 )
   R.ON.BODY.2                          := ( 13.803, -50.556, 32.433 )
   DISTANCE                             := '5.06'
UP
CREATE SPHERICAL.JOINT
   NAME                                 := 'SPH.LFL'
   BODY.1.NAME                          := 'ARM.LFL'
   BODY.2.NAME                          := 'WHEEL.FL'
   P.ON.BODY.1                          := ( -30.965, -39.180, 26.120 )
   P.ON.BODY.2                          := ( -30.965, -39.180, 26.120 )
   Q.ON.BODY.1                          := ( -30.757, -39.232, 27.097 )
   Q.ON.BODY.2                          := ( -28.170, -39.868, 39.254 )
   R.ON.BODY.1                          := ( -31.943, -39.180, 26.328 )
   R.ON.BODY.2                          := ( -44.099, -39.180, 28.915 )
   NODE.1                               := '0'
   NODE.2                               := '0'
UP
CREATE SPHERICAL.JOINT
   NAME                                 := 'SPH.LFR'
   BODY.1.NAME                          := 'ARM.LFR'
   BODY.2.NAME                          := 'WHEEL.FR'
   P.ON.BODY.1                          := ( 30.965, -39.180, 26.120 )
```

```
    P.ON.BODY.2                        := ( 30.965, -39.180, 26.120 )
    Q.ON.BODY.1                        := ( 30.757, -39.232, 27.097 )
    Q.ON.BODY.2                        := ( 28.170, -39.868, 39.254 )
    R.ON.BODY.1                        := ( 31.943, -39.180, 26.328 )
    R.ON.BODY.2                        := ( 44.099, -39.180, 28.915 )
    NODE.1                             := '0'
    NODE.2                             := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                               := 'SPH.LRL'
    BODY.1.NAME                        := 'ARM.LRL'
    BODY.2.NAME                        := 'WHEEL.RL'
    P.ON.BODY.1                        := ( -30.965, -169.370, 26.120 )
    P.ON.BODY.2                        := ( -30.965, -169.370, 26.120 )
    Q.ON.BODY.1                        := ( -30.757, -169.422, 27.097 )
    Q.ON.BODY.2                        := ( -28.170, -169.370, 39.270 )
    R.ON.BODY.1                        := ( -31.943, -169.370, 26.328 )
    R.ON.BODY.2                        := ( -44.115, -169.370, 28.915 )
    NODE.1                             := '0'
    NODE.2                             := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                               := 'SPH.LRR'
    BODY.1.NAME                        := 'ARM.LRR'
    BODY.2.NAME                        := 'WHEEL.RR'
    P.ON.BODY.1                        := ( 30.965, -169.370, 26.120 )
    P.ON.BODY.2                        := ( 30.965, -169.370, 26.120 )
    Q.ON.BODY.1                        := ( 30.757, -169.422, 27.097 )
    Q.ON.BODY.2                        := ( 28.170, -169.370, 39.270 )
    R.ON.BODY.1                        := ( 31.943, -169.370, 26.328 )
    R.ON.BODY.2                        := ( 44.115, -169.370, 28.915 )
    NODE.1                             := '0'
    NODE.2                             := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                               := 'SPH.UFL'
    BODY.1.NAME                        := 'ARM.UFL'
    BODY.2.NAME                        := 'WHEEL.FL'
    P.ON.BODY.1                        := ( -28.170, -39.868, 39.254 )
    P.ON.BODY.2                        := ( -28.170, -39.868, 39.254 )
    Q.ON.BODY.1                        := ( -27.962, -39.920, 40.231 )
    Q.ON.BODY.2                        := ( -25.375, -40.556, 52.388 )
    R.ON.BODY.1                        := ( -29.148, -39.868, 39.462 )
    R.ON.BODY.2                        := ( -41.304, -39.868, 42.049 )
    NODE.1                             := '0'
    NODE.2                             := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                               := 'SPH.UFR'
    BODY.1.NAME                        := 'ARM.UFR'
    BODY.2.NAME                        := 'WHEEL.FR'
    P.ON.BODY.1                        := ( 28.170, -39.868, 39.254 )
    P.ON.BODY.2                        := ( 28.170, -39.868, 39.254 )
    Q.ON.BODY.1                        := ( 27.962, -39.920, 40.231 )
    Q.ON.BODY.2                        := ( 25.375, -40.556, 52.388 )
    R.ON.BODY.1                        := ( 29.148, -39.868, 39.462 )
    R.ON.BODY.2                        := ( 41.304, -39.868, 42.049 )
    NODE.1                             := '0'
    NODE.2                             := '0'
UP
```

```
CREATE SPHERICAL.JOINT
   NAME                              := 'SPH.URL'
   BODY.1.NAME                       := 'ARM.URL'
   BODY.2.NAME                       := 'WHEEL.RL'
   P.ON.BODY.1                       := ( -28.170, -169.370, 39.270 )
   P.ON.BODY.2                       := ( -28.170, -169.370, 39.270 )
   Q.ON.BODY.1                       := ( -25.375, -169.370, 52.420 )
   Q.ON.BODY.2                       := ( -25.375, -169.370, 52.420 )
   R.ON.BODY.1                       := ( -41.320, -169.370, 42.065 )
   R.ON.BODY.2                       := ( -41.320, -169.370, 42.065 )
   NODE.1                            := '0'
   NODE.2                            := '0'
UP
CREATE SPHERICAL.JOINT
   NAME                              := 'SPH.URR'
   BODY.1.NAME                       := 'ARM.URR'
   BODY.2.NAME                       := 'WHEEL.RR'
   P.ON.BODY.1                       := ( 28.170, -169.370, 39.270 )
   P.ON.BODY.2                       := ( 28.170, -169.370, 39.270 )
   Q.ON.BODY.1                       := ( 25.375, -169.370, 52.420 )
   Q.ON.BODY.2                       := ( 25.375, -169.370, 52.420 )
   R.ON.BODY.1                       := ( 41.320, -169.370, 42.065 )
   R.ON.BODY.2                       := ( 41.320, -169.370, 42.065 )
   NODE.1                            := '0'
   NODE.2                            := '0'
UP
CREATE SPHERICAL.JOINT
   NAME                              := 'TRAILER.HITCH'
   BODY.1.NAME                       := 'CHASSIS'
   BODY.2.NAME                       := 'TRAILER.CHASSIS'
   P.ON.BODY.1                       := ( 0.0, -206.37, 33.38 )
   P.ON.BODY.2                       := ( 0.0, -206.37, 33.38 )
   Q.ON.BODY.1                       := ( 0.0, -206.37, 34.38 )
   Q.ON.BODY.2                       := ( 0.0, -206.37, 34.38 )
   R.ON.BODY.1                       := ( 1.0, -206.37, 33.38 )
   R.ON.BODY.2                       := ( 1.0, -206.37, 33.38 )
   NODE.1                            := '0'
   NODE.2                            := '0'
UP
CREATE TRANSLATIONAL.JOINT
   NAME                              := 'TRAILER.TRANS'
   BODY.1.NAME                       := 'TRAILER.CHASSIS'
   BODY.2.NAME                       := 'TRAILER.DUMMY'
   P.ON.BODY.1                       := ( 0.0, -305.37, 32.88 )
   P.ON.BODY.2                       := ( 0.0, -305.37, 32.88 )
   Q.ON.BODY.1                       := ( 0.0, -305.37, 35.14 )
   Q.ON.BODY.2                       := ( 0.0, -305.37, 35.14 )
   R.ON.BODY.1                       := ( 1.0, -305.37, 32.88 )
   R.ON.BODY.2                       := ( 1.0, -305.37, 32.88 )
   NODE.1                            := '0'
   NODE.2                            := '0'
UP
CREATE UNIVERSAL.JOINT
   NAME                              := 'PITMAN.UNIV'
   BODY.1.NAME                       := 'PITMAN.ARM'
   BODY.2.NAME                       := 'STEERING.LINK'
   P.ON.BODY.1                       := ( -9.811, -50.556, 32.433 )
   P.ON.BODY.2                       := ( -9.811, -50.556, 32.433 )
   Q.ON.BODY.1                       := ( -9.811, -50.239, 33.381 )
   Q.ON.BODY.2                       := ( -9.811, -49.608, 32.116 )
```

```
    R.ON.BODY.1                     := ( -8.811, -50.556, 32.433 )
    R.ON.BODY.2                     := ( -8.811, -50.556, 32.433 )
    NODE.1                          := '0'
    NODE.2                          := '0'

UP
CREATE BODY
    NAME                            := 'CHASSIS'
    CENTER.OF.GRAVITY               := ( 0.585, -123.170, 63.064 )
    TYPE.ANGULAR.COORD              := 'BRYANT'
    ANGLE.1                         := '0.0'
    ANGLE.2                         := '0.0'
    ANGLE.3                         := '0.0'
    FIXED.TO.GROUND                 := 'FALSE'
    MASS                            := '20.049'
    INERTIA.XXL                     := '52680.0'
    INERTIA.YYL                     := '13320.0'
    INERTIA.ZZL                     := '56280.0'
    INERTIA.XYL                     := '0.0'
    INERTIA.XZL                     := '0.0'
    INERTIA.YZL                     := '0.0'
    XG.FORCE                        := '0.0'
    YG.FORCE                        := '0.0'
    ZG.FORCE                        := '0.0'
    XL.TORQUE                       := '0.0'
    YL.TORQUE                       := '0.0'
    ZL.TORQUE                       := '0.0'
    CURVE.XGF                       := 'NONE'
    CURVE.YGF                       := 'NONE'
    CURVE.ZGF                       := 'NONE'
    CURVE.XLT                       := 'NONE'
    CURVE.YLT                       := 'NONE'
    CURVE.ZLT                       := 'NONE'
    SIGN.E0                         := 'POSITIVE'
    ANGULAR.UNITS                   := 'DEGREES'
    FLEXIBLE                        := 'FALSE'
    SUPERELEMENT                    := 'FALSE'
UP
CREATE BODY
    NAME                            := 'ARM.LFL'
    CENTER.OF.GRAVITY               := ( -21.5275, -37.78, 28.445 )
    TYPE.ANGULAR.COORD              := 'BRYANT'
    ANGLE.1                         := '0.0'
    ANGLE.2                         := '-13.84'
    ANGLE.3                         := '0.0'
    FIXED.TO.GROUND                 := 'FALSE'
    MASS                            := '0.0932'
    INERTIA.XXL                     := '1.0'
    INERTIA.YYL                     := '1.0'
    INERTIA.ZZL                     := '1.0'
    INERTIA.XYL                     := '0.0'
    INERTIA.XZL                     := '0.0'
    INERTIA.YZL                     := '0.0'
    XG.FORCE                        := '0.0'
    YG.FORCE                        := '0.0'
    ZG.FORCE                        := '0.0'
    XL.TORQUE                       := '0.0'
    YL.TORQUE                       := '0.0'
    ZL.TORQUE                       := '0.0'
    CURVE.XGF                       := 'NONE'
```

```
   CURVE.YGF                              := 'NONE'
   CURVE.ZGF                              := 'NONE'
   CURVE.XLT                              := 'NONE'
   CURVE.YLT                              := 'NONE'
   CURVE.ZLT                              := 'NONE'
   SIGN.E0                                := 'POSITIVE'
   ANGULAR.UNITS                          := 'DEGREES'
   FLEXIBLE                               := 'FALSE'
   SUPERELEMENT                           := 'FALSE'
UP
CREATE BODY
   NAME                                   := 'ARM.LFR'
   CENTER.OF.GRAVITY                      := ( 21.5275, -37.78, 28.445 )
   TYPE.ANGULAR.COORD                     := 'BRYANT'
   ANGLE.1                                := '0.0'
   ANGLE.2                                := '13.84'
   ANGLE.3                                := '0.0'
   FIXED.TO.GROUND                        := 'FALSE'
   MASS                                   := '0.0932'
   INERTIA.XXL                            := '1.0'
   INERTIA.YYL                            := '1.0'
   INERTIA.ZZL                            := '1.0'
   INERTIA.XYL                            := '0.0'
   INERTIA.XZL                            := '0.0'
   INERTIA.YZL                            := '0.0'
   XG.FORCE                               := '0.0'
   YG.FORCE                               := '0.0'
   ZG.FORCE                               := '0.0'
   XL.TORQUE                              := '0.0'
   YL.TORQUE                              := '0.0'
   ZL.TORQUE                              := '0.0'
   CURVE.XGF                              := 'NONE'
   CURVE.YGF                              := 'NONE'
   CURVE.ZGF                              := 'NONE'
   CURVE.XLT                              := 'NONE'
   CURVE.YLT                              := 'NONE'
   CURVE.ZLT                              := 'NONE'
   SIGN.E0                                := 'POSITIVE'
   ANGULAR.UNITS                          := 'DEGREES'
   FLEXIBLE                               := 'FALSE'
   SUPERELEMENT                           := 'FALSE'
UP
CREATE BODY
   NAME                                   := 'ARM.LRL'
   CENTER.OF.GRAVITY                      := ( -21.5275, -170.77, 28.445 )
   TYPE.ANGULAR.COORD                     := 'BRYANT'
   ANGLE.1                                := '0.0'
   ANGLE.2                                := '-13.84'
   ANGLE.3                                := '0.0'
   FIXED.TO.GROUND                        := 'FALSE'
   MASS                                   := '0.0932'
   INERTIA.XXL                            := '1.0'
   INERTIA.YYL                            := '1.0'
   INERTIA.ZZL                            := '1.0'
   INERTIA.XYL                            := '0.0'
   INERTIA.XZL                            := '0.0'
   INERTIA.YZL                            := '0.0'
   XG.FORCE                               := '0.0'
   YG.FORCE                               := '0.0'
   ZG.FORCE                               := '0.0'
```

```
    XL.TORQUE                               := '0.0'
    YL.TORQUE                               := '0.0'
    ZL.TORQUE                               := '0.0'
    CURVE.XGF                               := 'NONE'
    CURVE.YGF                               := 'NONE'
    CURVE.ZGF                               := 'NONE'
    CURVE.XLT                               := 'NONE'
    CURVE.YLT                               := 'NONE'
    CURVE.ZLT                               := 'NONE'
    SIGN.E0                                 := 'POSITIVE'
    ANGULAR.UNITS                           := 'DEGREES'
    FLEXIBLE                                := 'FALSE'
    SUPERELEMENT                            := 'FALSE'
UP
CREATE BODY
    NAME                                    := 'ARM.LRR'
    CENTER.OF.GRAVITY                       := ( 21.5275, -170.77, 28.445 )
    TYPE.ANGULAR.COORD                      := 'BRYANT'
    ANGLE.1                                 := '0.0'
    ANGLE.2                                 := '13.84'
    ANGLE.3                                 := '0.0'
    FIXED.TO.GROUND                         := 'FALSE'
    MASS                                    := '0.0932'
    INERTIA.XXL                             := '1.0'
    INERTIA.YYL                             := '1.0'
    INERTIA.ZZL                             := '1.0'
    INERTIA.XYL                             := '0.0'
    INERTIA.XZL                             := '0.0'
    INERTIA.YZL                             := '0.0'
    XG.FORCE                                := '0.0'
    YG.FORCE                                := '0.0'
    ZG.FORCE                                := '0.0'
    XL.TORQUE                               := '0.0'
    YL.TORQUE                               := '0.0'
    ZL.TORQUE                               := '0.0'
    CURVE.XGF                               := 'NONE'
    CURVE.YGF                               := 'NONE'
    CURVE.ZGF                               := 'NONE'
    CURVE.XLT                               := 'NONE'
    CURVE.YLT                               := 'NONE'
    CURVE.ZLT                               := 'NONE'
    SIGN.E0                                 := 'POSITIVE'
    ANGULAR.UNITS                           := 'DEGREES'
    FLEXIBLE                                := 'FALSE'
    SUPERELEMENT                            := 'FALSE'
UP
CREATE BODY
    NAME                                    := 'ARM.UFL'
    CENTER.OF.GRAVITY                       := ( -23.1765, -41.935, 39.3445 )
    TYPE.ANGULAR.COORD                      := 'BRYANT'
    ANGLE.1                                 := '12.557'
    ANGLE.2                                 := '0.0'
    ANGLE.3                                 := '-8.209'
    FIXED.TO.GROUND                         := 'FALSE'
    MASS                                    := '0.0311'
    INERTIA.XXL                             := '1.0'
    INERTIA.YYL                             := '1.0'
    INERTIA.ZZL                             := '1.0'
    INERTIA.XYL                             := '0.0'
    INERTIA.XZL                             := '0.0'
```

```
   INERTIA.YZL                          := '0.0'
   XG.FORCE                             := '0.0'
   YG.FORCE                             := '0.0'
   ZG.FORCE                             := '0.0'
   XL.TORQUE                            := '0.0'
   YL.TORQUE                            := '0.0'
   ZL.TORQUE                            := '0.0'
   CURVE.XGF                            := 'NONE'
   CURVE.YGF                            := 'NONE'
   CURVE.ZGF                            := 'NONE'
   CURVE.XLT                            := 'NONE'
   CURVE.YLT                            := 'NONE'
   CURVE.ZLT                            := 'NONE'
   SIGN.E0                              := 'POSITIVE'
   ANGULAR.UNITS                        := 'DEGREES'
   FLEXIBLE                             := 'FALSE'
   SUPERELEMENT                         := 'FALSE'
UP
CREATE BODY
   NAME                                 := 'ARM.UFR'
   CENTER.OF.GRAVITY                    := ( 23.1765, -41.935, 39.3445 )
   TYPE.ANGULAR.COORD                   := 'BRYANT'
   ANGLE.1                              := '12.557'
   ANGLE.2                              := '0.0'
   ANGLE.3                              := '8.209'
   FIXED.TO.GROUND                      := 'FALSE'
   MASS                                 := '0.0311'
   INERTIA.XXL                          := '1.0'
   INERTIA.YYL                          := '1.0'
   INERTIA.ZZL                          := '1.0'
   INERTIA.XYL                          := '0.0'
   INERTIA.XZL                          := '0.0'
   INERTIA.YZL                          := '0.0'
   XG.FORCE                             := '0.0'
   YG.FORCE                             := '0.0'
   ZG.FORCE                             := '0.0'
   XL.TORQUE                            := '0.0'
   YL.TORQUE                            := '0.0'
   ZL.TORQUE                            := '0.0'
   CURVE.XGF                            := 'NONE'
   CURVE.YGF                            := 'NONE'
   CURVE.ZGF                            := 'NONE'
   CURVE.XLT                            := 'NONE'
   CURVE.YLT                            := 'NONE'
   CURVE.ZLT                            := 'NONE'
   SIGN.E0                              := 'POSITIVE'
   ANGULAR.UNITS                        := 'DEGREES'
   FLEXIBLE                             := 'FALSE'
   SUPERELEMENT                         := 'FALSE'
UP
CREATE BODY
   NAME                                 := 'ARM.URL'
   CENTER.OF.GRAVITY                    := ( -23.1825, -165.875, 39.4625 )
   TYPE.ANGULAR.COORD                   := 'BRYANT'
   ANGLE.1                              := '0.0'
   ANGLE.2                              := '-2.21'
   ANGLE.3                              := '0.0'
   FIXED.TO.GROUND                      := 'FALSE'
   MASS                                 := '0.0311'
   INERTIA.XXL                          := '1.0'
```

```
   INERTIA.YYL                    := '1.0'
   INERTIA.ZZL                    := '1.0'
   INERTIA.XYL                    := '0.0'
   INERTIA.XZL                    := '0.0'
   INERTIA.YZL                    := '0.0'
   XG.FORCE                       := '0.0'
   YG.FORCE                       := '0.0'
   ZG.FORCE                       := '0.0'
   XL.TORQUE                      := '0.0'
   YL.TORQUE                      := '0.0'
   ZL.TORQUE                      := '0.0'
   CURVE.XGF                      := 'NONE'
   CURVE.YGF                      := 'NONE'
   CURVE.ZGF                      := 'NONE'
   CURVE.XLT                      := 'NONE'
   CURVE.YLT                      := 'NONE'
   CURVE.ZLT                      := 'NONE'
   SIGN.E0                        := 'POSITIVE'
   ANGULAR.UNITS                  := 'DEGREES'
   FLEXIBLE                       := 'FALSE'
   SUPERELEMENT                   := 'FALSE'
UP
CREATE BODY
   NAME                           := 'ARM.URR'
   CENTER.OF.GRAVITY              := ( 23.1825, -165.875, 39.4625 )
   TYPE.ANGULAR.COORD             := 'BRYANT'
   ANGLE.1                        := '0.0'
   ANGLE.2                        := '2.21'
   ANGLE.3                        := '0.0'
   FIXED.TO.GROUND                := 'FALSE'
   MASS                           := '0.0311'
   INERTIA.XXL                    := '1.0'
   INERTIA.YYL                    := '1.0'
   INERTIA.ZZL                    := '1.0'
   INERTIA.XYL                    := '0.0'
   INERTIA.XZL                    := '0.0'
   INERTIA.YZL                    := '0.0'
   XG.FORCE                       := '0.0'
   YG.FORCE                       := '0.0'
   ZG.FORCE                       := '0.0'
   XL.TORQUE                      := '0.0'
   YL.TORQUE                      := '0.0'
   ZL.TORQUE                      := '0.0'
   CURVE.XGF                      := 'NONE'
   CURVE.YGF                      := 'NONE'
   CURVE.ZGF                      := 'NONE'
   CURVE.XLT                      := 'NONE'
   CURVE.YLT                      := 'NONE'
   CURVE.ZLT                      := 'NONE'
   SIGN.E0                        := 'POSITIVE'
   ANGULAR.UNITS                  := 'DEGREES'
   FLEXIBLE                       := 'FALSE'
   SUPERELEMENT                   := 'FALSE'
UP
CREATE BODY
   NAME                           := 'WHEEL.FL'
   CENTER.OF.GRAVITY              := ( -35.815, -39.37, 29.735 )
   TYPE.ANGULAR.COORD             := 'BRYANT'
   ANGLE.1                        := '0.0'
   ANGLE.2                        := '0.0'
```

```
   ANGLE.3                                 := '-0.246'
   FIXED.TO.GROUND                         := 'FALSE'
   MASS                                    := '0.5047'
   INERTIA.XXL                             := '1.0'
   INERTIA.YYL                             := '1.0'
   INERTIA.ZZL                             := '1.0'
   INERTIA.XYL                             := '0.0'
   INERTIA.XZL                             := '0.0'
   INERTIA.YZL                             := '0.0'
   XG.FORCE                                := '0.0'
   YG.FORCE                                := '0.0'
   ZG.FORCE                                := '0.0'
   XL.TORQUE                               := '0.0'
   YL.TORQUE                               := '0.0'
   ZL.TORQUE                               := '0.0'
   CURVE.XGF                               := 'NONE'
   CURVE.YGF                               := 'NONE'
   CURVE.ZGF                               := 'NONE'
   CURVE.XLT                               := 'NONE'
   CURVE.YLT                               := 'NONE'
   CURVE.ZLT                               := 'NONE'
   SIGN.E0                                 := 'POSITIVE'
   ANGULAR.UNITS                           := 'DEGREES'
   FLEXIBLE                                := 'FALSE'
   SUPERELEMENT                            := 'FALSE'
UP
CREATE BODY
   NAME                                    := 'WHEEL.FR'
   CENTER.OF.GRAVITY                       := ( 35.815, -39.37, 29.735 )
   TYPE.ANGULAR.COORD                      := 'BRYANT'
   ANGLE.1                                 := '0.0'
   ANGLE.2                                 := '0.0'
   ANGLE.3                                 := '0.246'
   FIXED.TO.GROUND                         := 'FALSE'
   MASS                                    := '0.5047'
   INERTIA.XXL                             := '1.0'
   INERTIA.YYL                             := '1.0'
   INERTIA.ZZL                             := '1.0'
   INERTIA.XYL                             := '0.0'
   INERTIA.XZL                             := '0.0'
   INERTIA.YZL                             := '0.0'
   XG.FORCE                                := '0.0'
   YG.FORCE                                := '0.0'
   ZG.FORCE                                := '0.0'
   XL.TORQUE                               := '0.0'
   YL.TORQUE                               := '0.0'
   ZL.TORQUE                               := '0.0'
   CURVE.XGF                               := 'NONE'
   CURVE.YGF                               := 'NONE'
   CURVE.ZGF                               := 'NONE'
   CURVE.XLT                               := 'NONE'
   CURVE.YLT                               := 'NONE'
   CURVE.ZLT                               := 'NONE'
   SIGN.E0                                 := 'POSITIVE'
   ANGULAR.UNITS                           := 'DEGREES'
   FLEXIBLE                                := 'FALSE'
   SUPERELEMENT                            := 'FALSE'
UP
CREATE BODY
   NAME                                    := 'WHEEL.RL'
```

```
   CENTER.OF.GRAVITY                    := ( -35.815, -169.37, 29.735 )
   TYPE.ANGULAR.COORD                   := 'BRYANT'
   ANGLE.1                              := '0.0'
   ANGLE.2                              := '0.0'
   ANGLE.3                              := '0.246'
   FIXED.TO.GROUND                      := 'FALSE'
   MASS                                 := '0.5046'
   INERTIA.XXL                          := '1.0'
   INERTIA.YYL                          := '1.0'
   INERTIA.ZZL                          := '1.0'
   INERTIA.XYL                          := '0.0'
   INERTIA.XZL                          := '0.0'
   INERTIA.YZL                          := '0.0'
   XG.FORCE                             := '0.0'
   YG.FORCE                             := '0.0'
   ZG.FORCE                             := '0.0'
   XL.TORQUE                            := '0.0'
   YL.TORQUE                            := '0.0'
   ZL.TORQUE                            := '0.0'
   CURVE.XGF                            := 'NONE'
   CURVE.YGF                            := 'NONE'
   CURVE.ZGF                            := 'NONE'
   CURVE.XLT                            := 'NONE'
   CURVE.YLT                            := 'NONE'
   CURVE.ZLT                            := 'NONE'
   SIGN.E0                              := 'POSITIVE'
   ANGULAR.UNITS                        := 'DEGREES'
   FLEXIBLE                             := 'FALSE'
   SUPERELEMENT                         := 'FALSE'
 ND
CREATE BODY
   NAME                                 := 'WHEEL.RR'
   CENTER.OF.GRAVITY                    := ( 35.815, -169.37, 29.735 )
   TYPE.ANGULAR.COORD                   := 'BRYANT'
   ANGLE.1                              := '0.0'
   ANGLE.2                              := '0.0'
   ANGLE.3                              := '-0.246'
   FIXED.TO.GROUND                      := 'FALSE'
   MASS                                 := '0.5046'
   INERTIA.XXL                          := '1.0'
   INERTIA.YYL                          := '1.0'
   INERTIA.ZZL                          := '1.0'
   INERTIA.XYL                          := '0.0'
   INERTIA.XZL                          := '0.0'
   INERTIA.YZL                          := '0.0'
   XG.FORCE                             := '0.0'
   YG.FORCE                             := '0.0'
   ZG.FORCE                             := '0.0'
   XL.TORQUE                            := '0.0'
   YL.TORQUE                            := '0.0'
   ZL.TORQUE                            := '0.0'
   CURVE.XGF                            := 'NONE'
   CURVE.YGF                            := 'NONE'
   CURVE.ZGF                            := 'NONE'
   CURVE.XLT                            := 'NONE'
   CURVE.YLT                            := 'NONE'
   CURVE.ZLT                            := 'NONE'
   SIGN.E0                              := 'POSITIVE'
   ANGULAR.UNITS                        := 'DEGREES'
   FLEXIBLE                             := 'FALSE'
```

```
   SUPERELEMENT                          := 'FALSE'
UP
CREATE BODY
   NAME                                  := 'PITMAN.ARM'
   CENTER.OF.GRAVITY                     := ( -9.811, -52.956, 33.236 )
   TYPE.ANGULAR.COORD                    := 'BRYANT'
   ANGLE.1                               := '-18.5'
   ANGLE.2                               := '0.0'
   ANGLE.3                               := '0.0'
   FIXED.TO.GROUND                       := 'FALSE'
   MASS                                  := '0.0129'
   INERTIA.XXL                           := '1.0'
   INERTIA.YYL                           := '1.0'
   INERTIA.ZZL                           := '1.0'
   INERTIA.XYL                           := '0.0'
   INERTIA.XZL                           := '0.0'
   INERTIA.YZL                           := '0.0'
   XG.FORCE                              := '0.0'
   YG.FORCE                              := '0.0'
   ZG.FORCE                              := '0.0'
   XL.TORQUE                             := '0.0'
   YL.TORQUE                             := '0.0'
   ZL.TORQUE                             := '0.0'
   CURVE.XGF                             := 'NONE'
   CURVE.YGF                             := 'NONE'
   CURVE.ZGF                             := 'NONE'
   CURVE.XLT                             := 'NONE'
   CURVE.YLT                             := 'NONE'
   CURVE.ZLT                             := 'NONE'
   SIGN.E0                               := 'POSITIVE'
   ANGULAR.UNITS                         := 'DEGREES'
   FLEXIBLE                              := 'FALSE'
   SUPERELEMENT                          := 'FALSE'
UP
CREATE BODY
   NAME                                  := 'STEERING.LINK'
   CENTER.OF.GRAVITY                     := ( 0.000, -50.556, 32.433 )
   TYPE.ANGULAR.COORD                    := 'BRYANT'
   ANGLE.1                               := '-18.5'
   ANGLE.2                               := '0.0'
   ANGLE.3                               := '0.0'
   FIXED.TO.GROUND                       := 'FALSE'
   MASS                                  := '.0518'
   INERTIA.XXL                           := '1.0'
   INERTIA.YYL                           := '1.0'
   INERTIA.ZZL                           := '1.0'
   INERTIA.XYL                           := '0.0'
   INERTIA.XZL                           := '0.0'
   INERTIA.YZL                           := '0.0'
   XG.FORCE                              := '0.0'
   YG.FORCE                              := '0.0'
   ZG.FORCE                              := '0.0'
   XL.TORQUE                             := '0.0'
   YL.TORQUE                             := '0.0'
   ZL.TORQUE                             := '0.0'
   CURVE.XGF                             := 'NONE'
   CURVE.YGF                             := 'NONE'
   CURVE.ZGF                             := 'NONE'
   CURVE.XLT                             := 'NONE'
   CURVE.YLT                             := 'NONE'
```

```
    CURVE.ZLT                          := 'NONE'
    SIGN.E0                            := 'POSITIVE'
    ANGULAR.UNITS                      := 'DEGREES'
    FLEXIBLE                           := 'FALSE'
    SUPERELEMENT                       := 'FALSE'
UP
CREATE BODY
    NAME                               := 'TRAILER.CHASSIS'
    CENTER.OF.GRAVITY                  := ( 0.0, -302.02, 54.38 )
    TYPE.ANGULAR.COORD                 := 'EULER'
    ANGLE.1                            := '0.0'
    ANGLE.2                            := '0.0'
    ANGLE.3                            := '0.0'
    FIXED.TO.GROUND                    := 'FALSE'
    MASS                               := '7.25'
    INERTIA.XXL                        := '10000.0'
    INERTIA.YYL                        := '2600.0'
    INERTIA.ZZL                        := '10000.0'
    INERTIA.XYL                        := '0.0'
    INERTIA.XZL                        := '0.0'
    INERTIA.YZL                        := '0.0'
    XG.FORCE                           := '0.0'
    YG.FORCE                           := '0.0'
    ZG.FORCE                           := '0.0'
    XL.TORQUE                          := '0.0'
    YL.TORQUE                          := '0.0'
    ZL.TORQUE                          := '0.0'
    CURVE.XGF                          := 'NONE'
    CURVE.YGF                          := 'NONE'
    CURVE.ZGF                          := 'NONE'
    CURVE.XLT                          := 'NONE'
    CURVE.YLT                          := 'NONE'
    CURVE.ZLT                          := 'NONE'
    SIGN.E0                            := 'POSITIVE'
    ANGULAR.UNITS                      := 'DEGREES'
    FLEXIBLE                           := 'FALSE'
    SUPERELEMENT                       := 'FALSE'
UP
CREATE BODY
    NAME                               := 'TRAILER.AXLE'
    CENTER.OF.GRAVITY                  := ( 0.0, -305.37, 27.88 )
    TYPE.ANGULAR.COORD                 := 'EULER'
    ANGLE.1                            := '0.0'
    ANGLE.2                            := '0.0'
    ANGLE.3                            := '0.0'
    FIXED.TO.GROUND                    := 'FALSE'
    MASS                               := '1.0'
    INERTIA.XXL                        := '50.0'
    INERTIA.YYL                        := '10.0'
    INERTIA.ZZL                        := '50.0'
    INERTIA.XYL                        := '0.0'
    INERTIA.XZL                        := '0.0'
    INERTIA.YZL                        := '0.0'
    XG.FORCE                           := '0.0'
    YG.FORCE                           := '0.0'
    ZG.FORCE                           := '0.0'
    XL.TORQUE                          := '0.0'
    YL.TORQUE                          := '0.0'
    ZL.TORQUE                          := '0.0'
    CURVE.XGF                          := 'NONE'
```

```
   CURVE.YGF                          := 'NONE'
   CURVE.ZGF                          := 'NONE'
   CURVE.XLT                          := 'NONE'
   CURVE.YLT                          := 'NONE'
   CURVE.ZLT                          := 'NONE'
   SIGN.E0                            := 'POSITIVE'
   ANGULAR.UNITS                      := 'DEGREES'
   FLEXIBLE                           := 'FALSE'
   SUPERELEMENT                       := 'FALSE'
UP
CREATE BODY
   NAME                               := 'TRAILER.DUMMY'
   CENTER.OF.GRAVITY                  := ( 0.0, -305.37, 32.88 )
   TYPE.ANGULAR.COORD                 := 'EULER'
   ANGLE.1                            := '0.0'
   ANGLE.2                            := '0.0'
   ANGLE.3                            := '0.0'
   FIXED.TO.GROUND                    := 'FALSE'
   MASS                               := '0.1'
   INERTIA.XXL                        := '1.0'
   INERTIA.YYL                        := '1.0'
   INERTIA.ZZL                        := '1.0'
   INERTIA.XYL                        := '0.0'
   INERTIA.XZL                        := '0.0'
   INERTIA.YZL                        := '0.0'
   XG.FORCE                           := '0.0'
   YG.FORCE                           := '0.0'
   ZG.FORCE                           := '0.0'
   XL.TORQUE                          := '0.0'
   YL.TORQUE                          := '0.0'
   ZL.TORQUE                          := '0.0'
   CURVE.XGF                          := 'NONE'
   CURVE.YGF                          := 'NONE'
   CURVE.ZGF                          := 'NONE'
   CURVE.XLT                          := 'NONE'
   CURVE.YLT                          := 'NONE'
   CURVE.ZLT                          := 'NONE'
   SIGN.E0                            := 'POSITIVE'
   ANGULAR.UNITS                      := 'DEGREES'
   FLEXIBLE                           := 'FALSE'
   SUPERELEMENT                       := 'FALSE'
UP
CREATE INITIAL.CONDITION
   NAME                               := 'INIT.CHASSIS.ORIEN'
   BODY.1.NAME                        := 'CHASSIS'
   BODY.2.NAME                        := 'NONE'
   ELEMENT.NAME                       := 'NONE'
   TYPE.INITIAL.COND                  := 'ORIENTATION'
   INITIAL.VALUE                      := '0.0'
   TIME.DERIVATIVE                    := '0.0'
   OMEGA.Y                            := '0.0'
   OMEGA.Z                            := '0.0'
   P.ON.BODY.1                        := ( 0.0, 0.0, 0.0 )
   P.ON.BODY.2                        := ( 0.0, 0.0, 0.0 )
   EXTRA.COORD                        := '0'
   ANGULAR.UNITS                      := 'DEGREES'

CREATE INITIAL.CONDITION
   NAME                               := 'INIT.CHASSIS.X'
   BODY.1.NAME                        := 'CHASSIS'
```

```
    BODY.2.NAME                         := 'NONE'
    ELEMENT.NAME                        := 'NONE'
    TYPE.INITIAL.COND                   := 'X'
    INITIAL.VALUE                       := '0.0'
    TIME.DERIVATIVE                     := '0.0'
    OMEGA.Y                             := '0.0'
    OMEGA.Z                             := '0.0'
    P.ON.BODY.1                         := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                         := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                         := '0'
    ANGULAR.UNITS                       := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                := 'INIT.CHASSIS.Y'
    BODY.1.NAME                         := 'CHASSIS'
    BODY.2.NAME                         := 'NONE'
    ELEMENT.NAME                        := 'NONE'
    TYPE.INITIAL.COND                   := 'Y'
    INITIAL.VALUE                       := '0.0'
    TIME.DERIVATIVE                     := '440.0'
    OMEGA.Y                             := '0.0'
    OMEGA.Z                             := '0.0'
    P.ON.BODY.1                         := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                         := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                         := '0'
    ANGULAR.UNITS                       := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                := 'INIT.CHASSIS.Z'
    BODY.1.NAME                         := 'CHASSIS'
    BODY.2.NAME                         := 'NONE'
    ELEMENT.NAME                        := 'NONE'
    TYPE.INITIAL.COND                   := 'Z'
    INITIAL.VALUE                       := '0.0'
    TIME.DERIVATIVE                     := '0.0'
    OMEGA.Y                             := '0.0'
    OMEGA.Z                             := '0.0'
    P.ON.BODY.1                         := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                         := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                         := '0'
    ANGULAR.UNITS                       := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                := 'INIT.WHEEL.FL'
    BODY.1.NAME                         := 'WHEEL.FL'
    BODY.2.NAME                         := 'NONE'
    ELEMENT.NAME                        := 'NONE'
    TYPE.INITIAL.COND                   := 'Z'
    INITIAL.VALUE                       := '0.0'
    TIME.DERIVATIVE                     := '0.0'
    OMEGA.Y                             := '0.0'
    OMEGA.Z                             := '0.0'
    P.ON.BODY.1                         := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                         := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                         := '0'
    ANGULAR.UNITS                       := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                := 'INIT.WHEEL.FR'
    BODY.1.NAME                         := 'WHEEL.FR'
```

```
   BODY.2.NAME                        := 'NONE'
   ELEMENT.NAME                       := 'NONE'
   TYPE.INITIAL.COND                  := 'Z'
   INITIAL.VALUE                      := '0.0'
   TIME.DERIVATIVE                    := '0.0'
   OMEGA.Y                            := '0.0'
   OMEGA.Z                            := '0.0'
   P.ON.BODY.1                        := ( 0.0, 0.0, 0.0 )
   P.ON.BODY.2                        := ( 0.0, 0.0, 0.0 )
   EXTRA.COORD                        := '0'
   ANGULAR.UNITS                      := 'DEGREES'
UP
CREATE INITIAL.CONDITION
   NAME                               := 'INIT.WHEEL.RL'
   BODY.1.NAME                        := 'WHEEL.RL'
   BODY.2.NAME                        := 'NONE'
   ELEMENT.NAME                       := 'NONE'
   TYPE.INITIAL.COND                  := 'Z'
   INITIAL.VALUE                      := '0.0'
   TIME.DERIVATIVE                    := '0.0'
   OMEGA.Y                            := '0.0'
   OMEGA.Z                            := '0.0'
   P.ON.BODY.1                        := ( 0.0, 0.0, 0.0 )
   P.ON.BODY.2                        := ( 0.0, 0.0, 0.0 )
   EXTRA.COORD                        := '0'
   ANGULAR.UNITS                      := 'DEGREES'
UP
CREATE INITIAL.CONDITION
   NAME                               := 'INIT.WHEEL.RR'
   BODY.1.NAME                        := 'WHEEL.RR'
   BODY.2.NAME                        := 'NONE'
   ELEMENT.NAME                       := 'NONE'
   TYPE.INITIAL.COND                  := 'Z'
   INITIAL.VALUE                      := '0.0'
   TIME.DERIVATIVE                    := '0.0'
   OMEGA.Y                            := '0.0'
   OMEGA.Z                            := '0.0'
   P.ON.BODY.1                        := ( 0.0, 0.0, 0.0 )
   P.ON.BODY.2                        := ( 0.0, 0.0, 0.0 )
   EXTRA.COORD                        := '0'
   ANGULAR.UNITS                      := 'DEGREES'
UP
CREATE INITIAL.CONDITION
   NAME                               := 'WHEEL.FL.ORIEN'
   BODY.1.NAME                        := 'WHEEL.FL'
   BODY.2.NAME                        := 'NONE'
   ELEMENT.NAME                       := 'NONE'
   TYPE.INITIAL.COND                  := 'E3'
   INITIAL.VALUE                      := '-0.002155'
   TIME.DERIVATIVE                    := '0.0'
   OMEGA.Y                            := '0.0'
   OMEGA.Z                            := '0.0'
   P.ON.BODY.1                        := ( 0.0, 0.0, 0.0 )
   P.ON.BODY.2                        := ( 0.0, 0.0, 0.0 )
   EXTRA.COORD                        := '0'
   ANGULAR.UNITS                      := 'DEGREES'
UP
CREATE INITIAL.CONDITION
   NAME                               := 'WHEEL.FR.ORIEN'
   BODY.1.NAME                        := 'WHEEL.FR'
```

```
    BODY.2.NAME                      := 'NONE'
    ELEMENT.NAME                     := 'NONE'
    TYPE.INITIAL.COND                := 'E3'
    INITIAL.VALUE                    := '0.002138'
    TIME.DERIVATIVE                  := '0.0'
    OMEGA.Y                          := '0.0'
    OMEGA.Z                          := '0.0'
    P.ON.BODY.1                      := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                      := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                      := '0'
    ANGULAR.UNITS                    := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                             := 'INITIAL.TRAILER.CH.ORIEN'
    BODY.1.NAME                      := 'TRAILER.CHASSIS'
    BODY.2.NAME                      := 'NONE'
    ELEMENT.NAME                     := 'NONE'
    TYPE.INITIAL.COND                := 'ORIENTATION'
    INITIAL.VALUE                    := '0.0'
    TIME.DERIVATIVE                  := '0.0'
    OMEGA.Y                          := '0.0'
    OMEGA.Z                          := '0.0'
    P.ON.BODY.1                      := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                      := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                      := '0'
    ANGULAR.UNITS                    := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                             := 'TRAILER.AXLE.VERTICAL'
    BODY.1.NAME                      := 'TRAILER.AXLE'
    BODY.2.NAME                      := 'NONE'
    ELEMENT.NAME                     := 'NONE'
    TYPE.INITIAL.COND                := 'Z'
    INITIAL.VALUE                    := '0.0'
    TIME.DERIVATIVE                  := '0.0'
    OMEGA.Y                          := '0.0'
    OMEGA.Z                          := '0.0'
    P.ON.BODY.1                      := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                      := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                      := '0'
    ANGULAR.UNITS                    := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                             := 'TRAILER.AXLE.Y.ORIEN'
    BODY.1.NAME                      := 'TRAILER.AXLE'
    BODY.2.NAME                      := 'NONE'
    ELEMENT.NAME                     := 'NONE'
    TYPE.INITIAL.COND                := 'E2'
    INITIAL.VALUE                    := '0.0'
    TIME.DERIVATIVE                  := '0.0'
    OMEGA.Y                          := '0.0'
    OMEGA.Z                          := '0.0'
    P.ON.BODY.1                      := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                      := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                      := '0'
    ANGULAR.UNITS                    := 'DEGREES'
UP
CREATE DRIVER
    NAME                             := 'DRIVER'
    BODY.1.NAME                      := 'NONE'
```

```
   BODY.2.NAME                     := 'NONE'
   TYPE.DRIVER                     := 'REL.ANGLE'
   DRIVING.FUNCTION                := 'GENERAL'
   FUNCTION.PARAMETERS             := ( 0.0, 0.0, 0.0, 0.0 )
   P.ON.BODY.1                     := ( 0.0, 0.0, 0.0 )
   P.ON.BODY.2                     := ( 0.0, 0.0, 0.0 )
   Q.ON.BODY.1                     := ( 0.0, 0.0, 1.0 )
   Q.ON.BODY.2                     := ( 0.0, 0.0, 1.0 )
   R.ON.BODY.1                     := ( 1.0, 0.0, 0.0 )
   R.ON.BODY.2                     := ( 1.0, 0.0, 0.0 )
   CURVE.DRIVER                    := 'TRAJECTORY'
   JOINT.NAME                      := 'PITMAN.REV'
   ANGULAR.UNITS                   := 'DEGREES'
UP
CREATE CURVE
   NAME                            := 'TIRE.COEF'
   TYPE.DATA                       := 'PAIRED.XY'
   SLOPE.LEFT                      := '4.000'
   SLOPE.RIGHT                     := '0.000'
   SCALE.X                         := '1.0'
   SCALE.Y                         := '1.0'
   START.X                         := '0.0'
   INCREMENT.X                     := '0.0'
   INTERPOLATION                   := 'CUBIC'
   DATA
     0.0000000000E+00 0.0000000000E+00 0.2000000000E-01 0.8000000000E-01
     0.4000000000E-01 0.2000000000     0.8000000000E-01 0.4950000000
     0.1050000000     0.7000000000     0.1250000000     0.7600000000
     0.1650000000     0.7950000000     0.2200000000     0.7950000000
     0.2950000000     0.7500000000     0.4300000000     0.7000000000
      1.000000000     0.6000000000
   ENDDATA
UP
CREATE CURVE
   NAME                            := 'BIAS.TIRE.20PSI'
   TYPE.DATA                       := 'PAIRED.XY'
   SLOPE.LEFT                      := '0.0'
   SLOPE.RIGHT                     := '1600.000'
   SCALE.X                         := '1.0'
   SCALE.Y                         := '1.0'
   START.X                         := '0.0'
   INCREMENT.X                     := '0.0'
   INTERPOLATION                   := 'CUBIC'
   DATA
     0.0000000000E+00 0.0000000000E+00 0.1000000000      66.67000000
     0.2000000000      125.0000000     0.3000000000      175.0000000
     0.4000000000      250.0000000     0.5000000000      375.0000000
     0.6000000000      475.0000000     0.7000000000      600.0000000
     0.8000000000      700.0000000      1.000000000      975.0000000
      1.200000000      1250.000000      1.400000000      1500.000000
      1.600000000      1800.000000      1.800000000      2100.000000
      2.000000000      2425.000000      2.200000000      2700.000000
      2.400000000      3125.000000      2.600000000      3350.000000
      2.800000000      3675.000000      3.000000000      3975.000000
      3.200000000      4300.000000
   ENDDATA
UP
CREATE CURVE
   NAME                            := 'BIAS.TIRE.30PSI'
   TYPE.DATA                       := 'PAIRED.XY'
```

```
   SLOPE.LEFT                              := '0.0'
   SLOPE.RIGHT                             := '2125.000'
   SCALE.X                                 := '1.0'
   SCALE.Y                                 := '1.0'
   START.X                                 := '0.0'
   INCREMENT.X                             := '0.0'
   INTERPOLATION                           := 'CUBIC'
   DATA
     0.0000000000E+00 0.0000000000E+00 0.1000000000      66.67000000
     0.2000000000      150.0000000     0.3000000000      225.0000000
     0.4000000000      325.0000000     0.5000000000      475.0000000
     0.6000000000      600.0000000     0.7000000000      725.0000000
     0.8000000000      900.0000000      1.000000000      1225.000000
      1.200000000      1600.000000      1.400000000      1950.000000
      1.600000000      2350.000000      1.800000000      2750.000000
      2.000000000      3150.000000      2.200000000      3550.000000
      2.400000000      3950.000000      2.600000000      4375.000000
      2.800000000      4800.000000      3.000000000      5225.000000
      3.200000000      5650.000000
   ENDDATA
UP
CREATE CURVE
   NAME                                    := 'TRAJECTORY'
   TYPE.DATA                               := 'INCREMENTAL.X'
   SLOPE.LEFT                              := '0.0'
   SLOPE.RIGHT                             := '0.0'
   SCALE.X                                 := '1.0'
   SCALE.Y                                 := '1.0'
   START.X                                 := '0.0'
   INCREMENT.X                             := '1000.0'
   INTERPOLATION                           := 'CUBIC'
   DATA
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
     0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
```

```
    0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
    0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
    0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
    0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
  ENDDATA
UP
CREATE CURVE
  NAME                              := 'RADIAL.TIRE.LT235.85R16'
  TYPE.DATA                         := 'PAIRED.XY'
  SLOPE.LEFT                        := '0.0'
  SLOPE.RIGHT                       := '1600.000'
  SCALE.X                           := '1.0'
  SCALE.Y                           := '0.82'
  START.X                           := '0.0'
  INCREMENT.X                       := '0.0'
  INTERPOLATION                     := 'LINEAR'
  DATA
    0.0000000000E+00 0.0000000000E+00 0.1000000000      66.67000000
    0.2000000000       125.0000000    0.3000000000      175.0000000
    0.4000000000       250.0000000    0.5000000000      375.0000000
    0.6000000000       475.0000000    0.7000000000      600.0000000
    0.8000000000       700.0000000     1.000000000      975.0000000
     1.200000000       1250.000000     1.400000000      1500.000000
     1.600000000       1800.000000     1.800000000      2100.000000
     2.000000000       2425.000000     2.200000000      2700.000000
     2.400000000       3125.000000     2.600000000      3350.000000
     2.800000000       3675.000000     3.000000000      3975.000000
     3.200000000       4300.000000
  ENDDATA
UP
CREATE CURVE
  NAME                              := 'TRAILER.SHOCK.CURVE'
  TYPE.DATA                         := 'PAIRED.XY'
  SLOPE.LEFT                        := '5.0'
  SLOPE.RIGHT                       := '5.0'
  SCALE.X                           := '1.0'
  SCALE.Y                           := '2.0'
  START.X                           := '0.0'
  INCREMENT.X                       := '0.0'
  INTERPOLATION                     := 'LINEAR'
  DATA
    -723.0000000     -4600.000000     -223.0000000     -2100.000000
    0.0000000000E+00 0.0000000000E+00  198.0000000      2100.000000
     700.0000000      4600.000000
  ENDDATA
UP
CREATE CURVE
  NAME                              := 'TRAILER.SPRING.CURVE'
  TYPE.DATA                         := 'PAIRED.XY'
  SLOPE.LEFT                        := '6400.0'
  SLOPE.RIGHT                       := '6400.0'
  SCALE.X                           := '1.0'
  SCALE.Y                           := '1.0'
  START.X                           := '0.0'
  INCREMENT.X                       := '0.0'
  INTERPOLATION                     := 'LINEAR'
  DATA
    -3.000000000     -7480.000000     -2.500000000     -4280.000000
    -1.500000000     -2360.000000     0.0000000000E+00 -1400.000000
     3.437000000      800.0000000      4.437000000      7200.000000
```

```
   ENDDATA
UP
CREATE CURVE
   NAME                                    := 'TRAILER.SPRING.FRICT'
   TYPE.DATA                               := 'PAIRED.XY'
   SLOPE.LEFT                              := '0.0'
   SLOPE.RIGHT                             := '0.0'
   SCALE.X                                 := '10.0'
   SCALE.Y                                 := '100.0'
   START.X                                 := '0.0'
   INCREMENT.X                             := '0.0'
   INTERPOLATION                           := 'LINEAR'
   DATA
     -10.00000000     -1.000000000     -8.000000000     -.9440000000
     -5.000000000     -.6250000000     -2.000000000     -.2960000000
     0.0000000000E+00 0.0000000000E+00  2.000000000     0.2960000000
      5.000000000     0.6250000000      8.000000000     0.9440000000
      10.00000000      1.000000000
   ENDDATA
UP
superi>
```

```
USER_INPUT FILE:
TERRAIN: flat Ground Data because NX = 0
2345678901234567890123456789012345678901234567890123456789012345678901234567890

Roll Stiffness (lbs/rad) :
140000.0
Fore-Aft Offset used to give some distance before entering terrain (YOFFSET)
 250.0
Vertical offset for each tire: (ZOFFSET(I),I=1,# of tires)
 12.73      12.73      12.73      12.73      13.56      13.56
Rotational Inertia of each wheel: (ROTINT(I),I=1,# of wheels)
 40.0       40.0       40.0       40.0       40.0       40.0
Run Flat Radius
 12.50
Run Flat Stiffness
10000.0
Run Flat Damping
  0.00
Trajectory Curve Name
TRAJECTORY
Speed Controller Command Vehicle Velocity:
440.00
Position error feedback gain PKP:
0.0
Velocity error feedback gain PKV:
500.0
Maximum output torque at each wheel @ 100% engine power TORMAX:
28620.0
Rotation Point about global Z to get new vehicle orientation
  0.0        0.0        0.0
Rotation Angle about global Z
  0.0
Lateral Force versus slip and vertical force - BIAS.TIRE.20PSI
   7    5
Slip Angle Data
  0.0        0.01745    0.03491    0.05236    0.06981    0.10470    0.2094
Vertical Force Data
  0.000   1000.000   2000.000   3000.000   4000.000
Lateral Force Data
  0.0        0.0        0.0        0.0        0.0        0.0        0.0
  0.0      230.000    422.000    578.000    680.000    902.000   1084.000
  0.0      296.000    546.000    752.000    962.000   1330.000   1865.000
  0.0      275.000    508.000    712.000    928.000   1293.000   2266.000
  0.0      249.000    435.000    575.000    726.000   1080.000   1976.000
Lateral Force versus slip and vertical force - BIAS.TIRE.28PSI
   7    5
Slip Angle Data
  0.0        0.01745    0.03491    0.05236    0.06981    0.10470    0.2094
Vertical Force Data
  0.000   1000.000   2000.000   3000.000   4000.000
Lateral Force Data
  0.0        0.0        0.0        0.0        0.0        0.0        0.0
  0.0      217.000    392.000    544.000    671.000    803.000   1018.000
  0.0      333.000    623.000    863.000   1101.000   1436.000   1924.000
  0.0      362.000    645.000    942.000   1191.000   1671.000   2463.000
  0.0      348.000    602.000    892.000   1142.000   1613.000   2625.000
Lateral Force versus slip and vertical force - Goodyear 8.75R16.5 85PSI
   8    5
Slip Angle Data
  0.0        0.01745    0.035      0.070      0.140      0.209      0.279    0.5
```

Vertical Force Data

0.000	804.0	1742.0	2680.0	3618.0

Lateral Force Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	99.8	192.5	329.5	557.6	666.2	740.75	740.5
0.0	223.0	397.7	693.0	1104.5	1302.5	1360.0	1360.0
0.0	309.5	557.8	1025.5	1614.5	1858.9	2390.5	2390.5
0.0	382.3	718.0	1303.5	2077.0	2343.1	2395.5	2395.5

Aligning Torque versus slip and vertical force - BIAS.TIRE.20PSI

7 15

Slip Angle Data

0.0	0.01745	0.03491	0.05236	0.06981	0.08727	0.1047

Vertical Force Data

0.000	179.840	517.040	854.240	1191.440	1528.640	1865.840	2203.040
2540.240	2877.440	3214.640	3551.840	3889.040	4226.240	4563.440	

Aligning Torque Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	58.08	78.410	96.800	77.440	67.760	58.080
0.0	116.160	156.820	193.600	154.880	135.520	116.160
0.0	232.320	313.635	387.200	309.760	271.040	232.320
0.0	387.200	619.530	696.970	696.970	658.250	619.530
0.0	542.090	933.000	1115.150	1161.600	1115.150	1084.200
0.0	774.410	1277.780	1548.820	1672.700	1672.700	1626.260
0.0	929.290	1548.820	2013.500	2168.300	2207.060	2245.800
0.0	1084.170	1858.580	2400.670	2710.400	2865.300	2942.756
0.0	1161.614	2168.350	2787.870	3175.080	3407.400	3562.280
0.0	1277.780	2323.230	3097.630	3639.700	4026.930	4182.800
0.0	1394.000	2555.550	3407.400	4065.650	4569.020	4801.340
0.0	1471.380	2710.433	3717.160	4491.570	4956.220	5420.866
0.0	1510.098	2787.870	3872.050	4723.890	5420.866	5885.512
0.0	1548.810	2942.760	4026.930	4956.220	5730.630	6195.280

Aligning Torque versus slip and vertical force - BIAS.TIRE.28PSI

7 15

Slip Angle Data

0.0	0.01745	0.03491	0.05236	0.06981	0.08727	0.1047

Vertical Force Data

0.000	179.840	517.040	854.240	1191.440	1528.640	1865.840	2203.040
2540.240	2877.440	3214.640	3551.840	3889.040	4226.240	4563.440	

Aligning Torque Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	19.360	38.721	58.080	58.080	38.721	38.721
0.0	38.720	77.441	116.162	226.162	77.441	77.441
0.0	77.441	154.882	232.323	232.323	154.882	154.882
0.0	232.323	464.646	542.087	542.087	464.646	464.646
0.0	464.646	774.410	851.851	851.851	851.851	851.851
0.0	619.528	1006.733	1239.056	1239.056	1239.056	1277.777
0.0	774.410	1316.497	1548.820	1703.702	1703.702	1781.143
0.0	929.292	1548.820	2013.466	2168.348	2245.789	2323.230
0.0	1084.175	1858.584	2400.671	2710.435	2787.876	2865.317
0.0	1161.615	2168.348	2787.876	3097.640	3329.963	3484.845
0.0	1316.497	2400.671	3097.640	3639.727	3949.491	4065.652
0.0	1393.938	2632.994	3407.404	4026.932	4414.137	4646.460
0.0	1471.379	2787.876	3717.168	4414.137	4878.783	5111.106
0.0	1548.820	2942.758	3949.491	4685.180	5265.988	5653.193

Aligning torque versus slip and vertical force - Goodyear 8.75R16.5 85PSI

8 5

Slip Angle Data

0.0	0.01745	0.035	0.070	0.140	0.209	0.279	0.5

Vertical force data

0.000	804.0	1742.0	2680.0	3618.0

Aligning torque data

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	48.0	131.4	144.6	154.8	78.0	18.6	18.6
0.0	208.2	367.2	519.0	421.2	25.8	72.6	72.6
0.0	409.2	709.2	1027.8	994.2	564.0	144.0	144.0
0.0	640.8	1092.6	1641.6	1650.6	913.8	336.0	336.0

NX,NY

0 2

X(I),I=1,NX

0.000	3.000	6.000	9.000	12.000	15.000	18.000	21.000
24.000	27.000	30.000	33.000	36.000	39.000	42.000	45.000
48.000	51.000	54.000	57.000	60.000	63.000	66.000	69.000
72.000	75.000	78.000	81.000	84.000	87.000	90.000	93.000
96.000	99.000	102.000	105.000	108.000	111.000	114.000	117.000
120.000	123.000	126.000	129.000	132.000	135.000	138.000	141.000
144.000	147.000	150.000	153.000	156.000	159.000	162.000	165.000
168.000	171.000	174.000	177.000	180.000	183.000	186.000	189.000
192.000	195.000	198.000	201.000	204.000	207.000	210.000	213.000
216.000	219.000	222.000	225.000	228.000	231.000	234.000	237.000
240.000	243.000	246.000	249.000	252.000	255.000	258.000	261.000
264.000	267.000	270.000	273.000	276.000	279.000	282.000	285.000
288.000	291.000	294.000	297.000	300.000	303.000	306.000	309.000
312.000	315.000	318.000	321.000	324.000	327.000	330.000	333.000
336.000	339.000	342.000	345.000	348.000	351.000	354.000	357.000
360.000	363.000	366.000	369.000	372.000	375.000	378.000	381.000
384.000	387.000	390.000	393.000	396.000	399.000	402.000	405.000
408.000	411.000	414.000	417.000	420.000	423.000	426.000	429.000
432.000	435.000	438.000	441.000	444.000	447.000	450.000	453.000
456.000	459.000	462.000	465.000	468.000	471.000	474.000	477.000
480.000	483.000	486.000	489.000	492.000	495.000	498.000	

Y(I),I=1,NY

37.500 -37.500

Z(I),I=1,NZ

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.159	0.756	1.356	1.956	2.556	3.156	3.756
4.356	4.956	5.548	5.840	6.000	6.000	6.000	6.000
6.000	6.000	6.000	6.000	5.759	5.348	4.756	4.156
3.556	2.956	2.356	1.756	1.156	0.556	0.040	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Z(I),I=1,NZ

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	

superi>

APPENDIX C

Tire Model FORTRAN Source Code

```
C---ROUTINE: FRC38 Calculate tire forces.

C============Author and Modification Section===========================
C
C  Author:       James A. Aardema, Rick Mousseau, Roger Wheahage
C
C  Date written: March 25, 1987
C
C  Written on:   Digital VAX Workstation II
C
C  Modifications:
C
C=====================================================================

C============Algorithm Description=====================================
C
C  Purpose and use:
C  Calculates the tire forces when a body has a tire attached.
C  The derivation assumes the vehicle is pointed along the global Y axis
C  initially and that the velocity vector is along that axis, and that
C  the global Z axis is veritcle.
C
C  Error conditions:     none
C
C  Machine dependencies: none
C
C  Called by: MM38.FOR
C
C=====================================================================

      SUBROUTINE FRC38 ( Q, QD, QDD, FRC, ITIR, TIR, RB, A, IA, NB,
     &                   NTR, MPTRS, NPTRS, NPRB, UDE, DUDE )
```

```
C===========Variable Descriptions===================================
C
C---Arguments passed------------------------------------------------
C
C  Q......Array of generalized coordinates.
C  QD.....Array of velocities.
C  QDD....Array of acceleration values.
C  FRC....Array of generalized forces.
C  ITIR...Array of integer data from this module.
C  TIR....Array of real data from this module.
C  RB.....Array of rigid body real data.
C  A......Vector of all real data.
C  IA.....Vector of all integer data.
C  NB.....Number of rigid bodies.
C  NTR....Number of tire elements.
C  NPTRS..Number of real data per element.
C  MPTRS..Number of integer data per element.
C  NPRB...Number of real data per rigid body.
C  UDE....Array of user differential equations, Position terms
C  DUDE...Array of user differential equations, Velocity terms

      IMPLICIT DOUBLE PRECISION (A-H,P-Z)

      INTEGER NTR,NPTRS,MPTRS,NPRB,NB,IA(0:1)
      INTEGER ITIR(MPTRS,NTR)

      DOUBLE PRECISION A(0:1),Q(7,1),QD(7,1),FRC(7,1),
     &          TIR(NPTRS,NTR), RB(NPRB,NB), QDD(7,1),
     &          UDE(NTR+NTR), DUDE(NTR+NTR)

C
C---COMMON blocks---------------------------------------------------
C
      INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]STEPHT.BLK'
      INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]PARAM.BLK'

C---STEPHT common Variables-----------------------------------------
C
C  H........Integration predictor step size.
C  HMAX.....Maximum integration predictor step size.
C  TSTART...Time at the start of the simulation.
C  TEND.....Time when simulation is to stop.
C  TSTEP....Integration step size.
C  T........Current time during the simulation.
C  HSTLEN...Length of the history arrays.
C  HSTPTR...Pointer to the last used location in the history arrays.
C  HSTCNT...Count of the number of time steps for which integration
C           history was saved.
C  HSTH.....Past history of the integration time step.
C  HSTK.....Past history of the integration order.
C  HSTERR...Past history of the integration error estimate.
C
C
C----PARAM.BLK Common Variables-------------------------------------

C  This file contains a number of constants which are used in various
C  subroutines throughout the code and are stored here to insure
C  accuracy and make any changes easier.
```

```
C
C    PI.......pi
C    TWOPI....two times pi
C    DEGRAD...degrees per radian
C    MCHEPS...machine epsilon
C    BODMOD...number of the rigid body module
C    CRVMOD...number of the curve module
C    INPEPS...epsilon value used to check error in normalized input
C             values
C
C
      INCLUDE '[-.COMMON]POWERT.BLK'
      INCLUDE '[-.COMMON]ROLLBAR.BLK'
      INCLUDE '[-.COMMON]STEER.BLK'
      INCLUDE '[-.COMMON]SURF.BLK'
      INCLUDE '[-.COMMON]UPLOT.BLK'
      INCLUDE '[-.COMMON]WHEEL.BLK'

C---POWERT.BLK Common Variables---------------------------------------
C
C   PKP......Position error feedback gain
C   PKV......Velocity error feedback gain
C   VELCMD...Command velocity (constant)
C   TORMAX...Maximum Allowable Torque applied to each wheel
C   X0.......Initial X position of the vehicle in global coordinates
C   Y0.......Initial Y position of the vehicle in global coordinates
C
C---ROLLBAR.BLK Common Variables---------------------------------------
C
C   RSTIFF....Stiffness of the roll stabilizer bar

C---STEER.BLK Common Variables-----------------------------------------
C
C    ITRAJ.....Curve number of the trajectory
C    NDRVDE....Number of driver differential equations
C
C---SURF.BLK Common Variables:-----------------------------------------
C
C    IGROUND..Ground flag (logical)
C    NX.......Number of X data points in the terrain data file
C    NY.......Number of Y data points in the terrain data file
C    XX.......Array (DBLE) containing terrain X (longnitude) data points
C    YY.......Array (DBLE) containing terrain Y (latitude) data points
C    GRID.....Array (DBLE) containing terrain Z (elevation) data points
C    IPX......Array containing pointers to the latest grid X coordinate
C             for each wheel.  Initially set to 1 by READ_TERRAIN
C    IPY......Array containing pointers to the latest grid Y coordinate
C             for each wheel.  Initially set to 1 by READ_TERRAIN
C    UV.......Array (double precision) containing 3 unit vectors
C             which describes the grid element
C             UV(C,1,I) Unit vector in the X-Z plane of the grid
C             UV(C,2,I) Unit vector in the Y-Z plane of the grid
C             UV(C,3,I) Unit vector normal to the plane of the grid
C    GDE1.....UNKNOWN
C    YOFFSET..Fore-Aft distance before vehicle enters desired trajectory
C             This allows for some initial vehicle settling
C    ZOFFSET..Elvation offset for each wheel.  This distance is added
C             to the surface elevation.
C
C---UPLOT.BLK Common Variables-----------------------------------------
```

```
C
C   UPLOT....Array for storing user variables
C   NPLOT....Number of plot variables used
C
C---WHEEL.BLK Common Variables------------------------------------------
C

C   NWHDE....Number of wheel differention equations NWHDE = 2 * NCT
C   UDE0.....Initial condition of the wheel differential equations
C   ROTINT...Rotational Inertia of each wheel
C   WHDAMP...Rotatinal Damping of each wheel
C   WHLBOD...Body number the tire is attached to
C
C---Local variables-----------------------------------------------------
C
C---Local Variables at process block 1----------------------------------
C
C  ACH.......Transformation array to convert local chassis coordinates
C            to global coordinates
C  ALGNTQ ...Aligning moment.
C  ETA    ...Local Y coordinate from body CG to tire center.
C  FLAT   ...Lateral force acting perpendicular to the tire.
C  FLONG  ...Longitudinal force acting in line with the tire.
C  FNORM  ...Normal tire force acting perpendicular to the road.
C  FX     ...Global X component of the tire force.
C  FXB    ...Local X component of the tire force.
C  FY     ...Global Y component of the tire force.
C  FYB    ...Local Y component of the tire force.
C  FZ     ...Global Z component of the tire force.
C  FZB    ...Local Z component of the tire force.
C  IBDY   ...Body number the tire is attached to.
C  OVERM.....Overturning moment.
C  RAD.......Radius of the tire.
C  SLIP......Slip angle of the tire.
C  TIREX.....Global X position of the tire center.
C  TIREY.....Global Y position of the tire center.
C  TIREZ.....Global Z position of the tire center.
C  TQETA.....Torque about the local eta axis.
C  TQXI......Torque about the local xi axis.
C  TQZETA....Torque about the local zeta axis.
C  VTIREX....Local X velocity of the tire/road interface.
C  VTIREY....Local Y velocity of the tire/road interface.
C  VTIREZ....Local Z velocity of the tire/road interface.
C  XI........Local X coordinate from body CG to tire center.
C  ZETA......Local Z coordinate from body CG to tire center.
C  NUSED.....Number of plot variables used before this time.
C  E0 - E3...Euler parameters

      INTEGER I, IBDY, ICHS, ITIRE(2), NUSED

      DOUBLE PRECISION XI,ETA,ZETA,ZETA2,RAD,ROLLM,OVERM,ZROAD,
     &                 AM(3,3),YAW,SYAW,CYAW,YAWB,TIREX,TIREY,
     &                 TIREZ,VTIRE1,VTIRE2,VTIRE3,VTIREX,VTIREY,
     &                 VTIREZ,FX,FY,FZ,FXB,FYB,FZB,TQXI,TQETA

      DOUBLE PRECISION TQZETA, FLAT, FNORM, TIRE1, TIRE2,
     &                 TIRE3, SLIP, GFRC, ALGNTQ,
     &                 S, FLONG, E0, E1, E2, E3,
     &                 OMEGAX, OMEGAY, OMEGAZ,
     &                 TIRECX, TIRECY, TIRECZ
```

```
C---Local Variables at Process Block 2--------------------------------
C
C    ACHS.....Chassis Transformation Matrix
C    POSCMD...Command Position
C    POS......Actual vehicle position
C    XD.......Global X chassis velocity
C    YD.......Global Y chassis velocity
C    ZD.......Global Z chassis velocity
C    YDCHS....Chassis Y velocity in body coordinates
C    ZDCHS....Chassis Z velocity in body coordinates
C    PITCH....Pitch angle
C    VEL......Actual vehicle velocity
C    POSERR...Position error
C    VELERR...Velocity error
C    FORCE....Controlled force to correct position and velocity errors
C    AVGRAD...Average Radius of each tire
C    TORQUE...Equivalent torque applied to each wheel
C
      DOUBLE PRECISION ACHS(3,3), POSCMD, POS, XD, YD, ZD,
     &                 YDCHS, ZDCHS, PITCH, VEL, POSERR,
     &                 VELERR, FORCE, AVGRAD, TORQUE

C---Local Variables at Process Block 3--------------------------------
C
C   ACHS.....Chassis Transformation Matrix
C   DELTAP...Array containing the X, Y, and Z global components of
C            a vector between the two lower control arms C.G.
C   DXCH.....The above vector along the chassis X axis
C   DZCH.....The above vector along the chassis Z axis
C   VECLEN...Length of the above vector
C   ANG......The angle between of the vector in the chassis X-Z plane
C   ARMFOR...Verticle arm force due to roll stabilization bar
C   CHTOR....Reaction Torque acting about the Chassis Y (fore-aft) Axis
C   TQ.......Reaction Torque in Global Coordinate System
C   TQE......Reaction Torque in Euler Parameter Coordinate System
C   FP.......Array containing the X, Y, and Z roll bar vertical force
C            in global coordinates

      DOUBLE PRECISION DELTAP(3), DXCH, DZCH, ANG, ARMFOR, FP(3),
     &                 CHTOR, TQ(3), TQE(4), VECLEN

C---Functions and subroutines-----------------------------------------

      DOUBLE PRECISION FSPLIN, CUBIC, CUBIC1

      EXTERNAL  TIREF, FSPLIN, CUBIC, CUBIC1, ETS

      INTRINSIC DSQRT, DSIN,   DCOS, DACOS, DASIN, DSIGN, DABS,
     &          DATAN, DATAN2, DMIN1

C==========Process Block==============================================

C---First get the number of plot variables used before this time
C   See USER_TSDA.FOR for others
C   NUSED must not be modified while in the DO LOOP

      NUSED = NPLOT                  ! Number of plot variables used thus far

C---For each tire do the following routine
```

```
      DO 1000 I = 1,NTR

C---Initialize local variables for convenience.

         IBDY  = ITIR(1,I)
         ICHS  = ITIR(2,I)
C        IUTIL = ITIR(3,I)
C        ITK   = ITIR(4,I)
C        ILNG  = ITIR(5,I)
C        ISTR  = ITIR(6,I)
C        TYPE  = ITIR(7,I)

         XI    = TIR(1,I)
         ETA   = TIR(2,I)
         ZETA  = TIR(3,I)
         RAD   = TIR(4,I)
C        RR    = TIR(5,I)
C        TD    = TIR(6,I)
C        TK    = TIR(7,I)
C        CALP  = TIR(8,I)
C        STRAGL= TIR(9,I)
C        MU    = TIR(10,I)

C                                                   global
C---Define the local to global transformation matrix,     [AM].
C                                                            local
         AM(1,1) = RB(38,IBDY)
         AM(2,1) = RB(39,IBDY)
         AM(3,1) = RB(40,IBDY)
         AM(1,2) = RB(41,IBDY)
         AM(2,2) = RB(42,IBDY)
         AM(3,2) = RB(43,IBDY)
         AM(1,3) = RB(44,IBDY)
         AM(2,3) = RB(45,IBDY)
         AM(3,3) = RB(46,IBDY)

C---Define the yaw angle of the axle or wheel center.
C   The result of DATAN2 is in radians.
C   The range of the result for DATAN2 is -pi < result > pi
C
C   Does this put limiations on the model???????????????????????????????????

         YAW = -DATAN2(AM(1,2),AM(2,2))
         SYAW = DSIN(YAW)
         CYAW = DCOS(YAW)

C---Define the vector from the body CG to the tire bottom in the
C   global system relative to the axle CG.
C   Update ZETA; Zeta is now the local Z coordinate from body CG to tire bottom.
C   This assumes that body positive Z axis is upward verticle.

         ZETA2 = ZETA
         ZETA  = ZETA - RAD
         TIREX = AM(1,1)*XI + AM(1,2)*ETA + AM(1,3)*ZETA
         TIREY = AM(2,1)*XI + AM(2,2)*ETA + AM(2,3)*ZETA
         TIREZ = AM(3,1)*XI + AM(3,2)*ETA + AM(3,3)*ZETA

C---Define the angular velocity of the body assoc with the wheel
```

```
      OMEGAX = RB(32,IBDY)
      OMEGAY = RB(33,IBDY)
      OMEGAZ = RB(34,IBDY)

C---Define vector between body CG and wheel center in global cordinates

      TIRECX = AM(1,1)*XI + AM(1,2)*ETA + AM(1,3)*ZETA2
      TIRECY = AM(2,1)*XI + AM(2,2)*ETA + AM(2,3)*ZETA2
      TIRECZ = AM(3,1)*XI + AM(3,2)*ETA + AM(3,3)*ZETA2

C---Define the global XYZ velocities of the axle or wheel center.
C   global [vtire]

       VTIRE1=QD(1,IBDY) - OMEGAZ*TIRECY +  OMEGAY*TIRECZ
       VTIRE2=QD(2,IBDY) + OMEGAZ*TIRECX -  OMEGAX*TIRECZ
       VTIRE3=QD(3,IBDY) - OMEGAY*TIRECX +  OMEGAX*TIRECY

C         VTIRE1 = QD(1,IBDY)
C         VTIRE2 = QD(2,IBDY)
C         VTIRE3 = QD(3,IBDY)


C---Transform the velocity vector to the road system.
C   road [vtire] = [AYAW] transpose * global [vtire]

      VTIREX = VTIRE1*CYAW + VTIRE2*SYAW
      VTIREY =-VTIRE1*SYAW + VTIRE2*CYAW
      VTIREZ = VTIRE3

C---Define the global position of the tire bottom.

      TIREX = TIREX + Q(1,IBDY)
      TIREY = TIREY + Q(2,IBDY)
      TIREZ = TIREZ + Q(3,IBDY)

C---Define the global position of the tire center.

      TIRE1 = TIREX + RAD*AM(1,3)
      TIRE2 = TIREY + RAD*AM(2,3)
      TIRE3 = TIREZ + RAD*AM(3,3)

C---Calculate the ground elevation if IGROUND flag is not equal to zero.
C   First intialize ground elevation to 0.0
C   Add verticle ground elevation offset

      ZROAD = 0.D0
      IF (IGROUND) THEN
          ZROAD=SURF(TIREY-YOFFSET,-TIREX,I)
      ENDIF
      ZROAD = ZROAD+ZOFFSET(I)

C---Save the values calculated thus far

      TIR(11,I) = YAW
      TIR(12,I) = VTIREX
      TIR(13,I) = VTIREY
      TIR(14,I) = VTIREZ
      TIR(15,I) = TIRE1
      TIR(16,I) = TIRE2
      TIR(17,I) = TIRE3
```

```
      TIR(18,I) = TIREX
      TIR(19,I) = TIREY
      TIR(20,I) = TIREZ
      TIR(21,I) = ZROAD

C---Calculate the tire forces.

      CALL TIREF ( I, Q, QD, QDD, FRC, ITIR, TIR, RB, A, IA,
     &             NB, NTR, MPTRS, NPTRS, NPRB, UDE, DUDE, NWHDE )


C---Get information for reporting later.

      DEFL   = TIR(22,I)
      FSPR   = TIR(23,I)
      FDAMP  = TIR(24,I)
      FNORM  = TIR(25,I)
      SLIP   = TIR(26,I)
      FLAT   = TIR(27,I)
      S      = TIR(28,I)
      FLONG  = TIR(29,I)
      GFRC   = TIR(30,I)
      PENRF  = TIR(31,I)
      FRF    = TIR(32,I)
      ALGNTQ = TIR(33,I)

C---Assign torque on tire due to longitudinal force to the wheel
C   angular acceleration intergrator to calculate new turning wheel veloctiy.
C   Assign result of acceleration integration to the wheel angular veloctiy
C   integrator to calculate new turning wheel postion.

      DUDE(I+NTR) = GFRC/ROTINT(I)
      DUDE(I)     = UDE(I+NTR)

C---Transform FLAT and FLONG from the road plane to global.

      FX  = FLAT*CYAW - FLONG*SYAW
      FY  = FLAT*SYAW + FLONG*CYAW
      FZ  = FNORM

C---Transform the global forces to the local body system.

      FXB = AM(1,1)*FX + AM(2,1)*FY + AM(3,1)*FZ
      FYB = AM(1,2)*FX + AM(2,2)*FY + AM(3,2)*FZ
      FZB = AM(1,3)*FX + AM(2,3)*FY + AM(3,3)*FZ

C---Calculate Sxf, the cross product of the S vector and the local force.
C   N' = S'F'  where N' ==> local torque
C                    S' ==> local vector from CG to point of force
C                    F' ==> local force

      TQXI   =                -ZETA*FYB + ETA*FZB
      TQETA  =  ZETA*FXB                - XI*FZB
      TQZETA = -ETA*FXB +  XI*FYB

C---Subtract the torque due the longitudinal tire forces because those
C   torques get applied to the wheel position and velocity integrators.

      TQXI   = TQXI - GFRC
```

```
C---Convert the local torques to the Euler parameter system using:
C                                        T                    T
C                                Np = 2L n'    or     Np = 2G n'
C   where N' is the local torques
C---and update the generalized force vector with the tire forces converted to
C   the global coordinate system. The last four elements are 2*G(T)*N.

         E0 = Q(4,IBDY)
         E1 = Q(5,IBDY)
         E2 = Q(6,IBDY)
         E3 = Q(7,IBDY)

         FRC(1,IBDY) = FRC(1,IBDY) + FX
         FRC(2,IBDY) = FRC(2,IBDY) + FY
         FRC(3,IBDY) = FRC(3,IBDY) + FZ
         FRC(4,IBDY) = FRC(4,IBDY) +
     &                 2.0D0 * (-E1*TQXI - E2*TQETA - E3*TQZETA)
         FRC(5,IBDY) = FRC(5,IBDY) +
     &                 2.0D0 * ( E0*TQXI - E3*TQETA + E2*TQZETA)
         FRC(6,IBDY) = FRC(6,IBDY) +
     &                 2.0D0 * ( E3*TQXI + E0*TQETA - E1*TQZETA)
         FRC(7,IBDY) = FRC(7,IBDY) +
     &                 2.0D0 * (-E2*TQXI + E1*TQETA + E0*TQZETA)

C---The aligning torque acts along the vertical axis and in the
C   vertical plane; not the local wheel plane.  For a point follower
C   type wheel model such as this the vertical axis is also the
C   global z axis

C---Transform the global aligning torque to euler parameter torques
C   using:                                T
C                                Np = 2G N
C   where N is now a global torque

         FRC(4,IBDY) = FRC(4,IBDY) - 2.0D0 * ( E3*ALGNTQ)
         FRC(5,IBDY) = FRC(5,IBDY) - 2.0D0 * ( E2*ALGNTQ)
         FRC(6,IBDY) = FRC(6,IBDY) + 2.0D0 * ( E1*ALGNTQ)
         FRC(7,IBDY) = FRC(7,IBDY) + 2.0D0 * ( E0*ALGNTQ)

C---Report out to report

         I1 = NUSED + I                 ! Start of user plot variables
         UPLOT(I1)      = YAW           ! Yaw angle of the Tire
         I2  = I1 + NTR
         UPLOT(I2)      = VTIREX        ! Tire Velocity in local X direction
         I3  = I2 + NTR
         UPLOT(I3)      = VTIREY        ! Tire Velocity in local Y direction
         I4  = I3 + NTR
         UPLOT(I4)      = VTIREZ        ! Tire Velocity in local Z direction
         I5  = I4 + NTR
         UPLOT(I5)      = TIRE1         ! Global X position of tire center
         I6  = I5 + NTR
         UPLOT(I6)      = TIRE2         ! Global Y position of tire center
         I7  = I6 + NTR
         UPLOT(I7)      = TIRE3         ! Global Z position of tire center
         I8  = I7 + NTR
         UPLOT(I8)      = TIREX         ! Global X position of tire bottom
         I9  = I8 + NTR
         UPLOT(I9)      = TIREY         ! Global Y position of tire bottom
         I10 = I9 + NTR
```

```
      UPLOT(I10)       = TIREZ       ! Global Z position of tire bottom
      I11 = I10 + NTR
      UPLOT(I11)       = ZROAD       ! Road or surface elevation
      I12 = I11 + NTR
      UPLOT(I12)       = DEFL        ! Wheel Penetration into surface
      I13 = I12 + NTR
      UPLOT(I13)       = FSPR        ! Wheel normal force due to penetration
      I14 = I13 + NTR
      UPLOT(I14)       = FDAMP       ! Wheel normal force due to pene rate
      I15 = I14 + NTR
      UPLOT(I15)       = FNORM       ! Normal force on wheel
      I16 = I15 + NTR
      UPLOT(I16)       = SLIP        ! Slip
      I17 = I16 + NTR
      UPLOT(I17)       = FLAT        ! Lateral force
      I18 = I17 + NTR
      UPLOT(I18)       = S           ! Longitudinal slip
      I19 = I18 + NTR
      UPLOT(I19)       = FLONG       ! Longitudinal force
      I20 = I19 + NTR
      UPLOT(I20)       = GFRC        ! Torque on turning wheel
      I21 = I20 + NTR
      UPLOT(I21)       = PENRF       ! Penetration into run flat assembly
      I22 = I21 + NTR
      UPLOT(I22)       = FRF         ! Run flat force
      I23 = I22 + NTR
      UPLOT(I23)       = ALGNTQ      ! Aligning Torque due to slip

C---End of routine calculation for a wheel. Continue for next wheel.

 1000 CONTINUE

C---Define more variables for user plot.

      UPLOT(1)=T                          ! Time
      NPLOT = I23                         ! Number of plot variables used so far

C==========Process Block 2================================================

C---Calculate torques nesscary to drive vehicle at specified speed------------

C     UDE(1)  :  Front left  wheel angular position
C     UDE(2)  :  Front right wheel angular position
C     UDE(3)  :  Rear  left  wheel angular position
C     UDE(4)  :  Rear  right wheel angular position
C     UDE(5)  :  Front left  wheel angular velocity
C     UDE(6)  :  Front right wheel angular velocity
C     UDE(7)  :  Rear  left  wheel angular velocity
C     UDE(8)  :  Rear  right wheel angular velocity

C---Get the chassis body number from one of the tire elements

      ICHS = ITIR(2,1)

C---Calculate the command vehicle postion

      POSCMD = VELCMD*T

C---Get the actual vehicle position ( the distance the vehicle travel thus far)
C   using the TRAJECTORY curve.  The vehicle position can be estimated knowing
```

```
C   the vehicle's current forward position and calculating the arclength of
C   the TRAJECTORY.  This is a good estimate if the vehicle is on course.

C       YPOS = Q(2,ICHS) - Y0
C       POS  = FSPLIN( YPOS, 0.0D0, ITRAJ, 1, A, IA, -2, 0 )

C---Get the chassis transformation matrix

      ACHS(1,1) = RB(38,ICHS)
      ACHS(2,1) = RB(39,ICHS)
      ACHS(3,1) = RB(40,ICHS)
      ACHS(1,2) = RB(41,ICHS)
      ACHS(2,2) = RB(42,ICHS)
      ACHS(3,2) = RB(43,ICHS)
      ACHS(1,3) = RB(44,ICHS)
      ACHS(2,3) = RB(45,ICHS)
      ACHS(3,3) = RB(46,ICHS)

C---Get the global velocity of the chassis

      XD = QD(1,ICHS)
      YD = QD(2,ICHS)
      ZD = QD(3,ICHS)

C---Transform to get the Y and Z velocity components in the chassis C.S.

      YDCHS = ACHS(1,2)*XD + ACHS(2,2)*YD + ACHS(3,2)*ZD
      ZDCHS = ACHS(1,3)*XD + ACHS(2,3)*YD + ACHS(3,3)*ZD

C---Get the vehicle pitch angle

      PITCH = -DATAN2(ACHS(2,3),ACHS(3,3))

C---Calculate the vehicle velocity in the Y direction and contained
C   in a horizontal plane

      VEL = YDCHS*DCOS(PITCH)-ZDCHS*DSIN(PITCH)

C---Calculate the position and veloctiy error

C       POSERR = POSCMD - POS
      VELERR = VELCMD - VEL

C---Calculate controlled force to correct position and velocity error

      FORCE = PKV*VELERR

C---Calculate the average tire radius

      AVGRAD = 0.0D0
      DO 200 I = 1,NTR
        AVGRAD = AVGRAD + (TIR(4,I)-TIR(22,I))
 200  CONTINUE
      AVGRAD = AVGRAD/4.0D0

C---Convert vehicle force to equivalent wheel torque at each
C---Use negative sign because a negative torque will result in
C   the wheel propelling the vehicle forward

      TORQUE = -FORCE*AVGRAD
```

```
C---Divide the torque evenly between all the wheels

      TORQUE = TORQUE/4.0D0

C---Limit the torque at each wheel

      IF ( TORQUE .GT.  TORMAX ) TORQUE =  TORMAX
      IF ( TORQUE .LT. -TORMAX ) TORQUE = -TORMAX

C---Append torques to each wheel for integration

      DUDE(5)   = TORQUE/ROTINT(1) + DUDE(5)
      DUDE(6)   = TORQUE/ROTINT(2) + DUDE(6)
      DUDE(7)   = TORQUE/ROTINT(3) + DUDE(7)
      DUDE(8)   = TORQUE/ROTINT(4) + DUDE(8)

C---Report out Torques

      UPLOT(NPLOT+1)   = UDE(1)
      UPLOT(NPLOT+2)   = UDE(2)
      UPLOT(NPLOT+3)   = UDE(3)
      UPLOT(NPLOT+4)   = UDE(4)
      UPLOT(NPLOT+5)   = UDE(5)
      UPLOT(NPLOT+6)   = UDE(6)
      UPLOT(NPLOT+7)   = UDE(7)
      UPLOT(NPLOT+8)   = UDE(8)
      UPLOT(NPLOT+9)   = DUDE(1)
      UPLOT(NPLOT+10)  = DUDE(2)
      UPLOT(NPLOT+11)  = DUDE(3)
      UPLOT(NPLOT+12)  = DUDE(4)
      UPLOT(NPLOT+13)  = DUDE(5)
      UPLOT(NPLOT+14)  = DUDE(6)
      UPLOT(NPLOT+15)  = DUDE(7)
      UPLOT(NPLOT+16)  = DUDE(8)
      UPLOT(NPLOT+17)  = POSCMD
      UPLOT(NPLOT+18)  = POS
      UPLOT(NPLOT+19)  = PITCH
      UPLOT(NPLOT+20)  = VEL
      UPLOT(NPLOT+21)  = POSERR
      UPLOT(NPLOT+22)  = VELERR
      UPLOT(NPLOT+23)  = FORCE
      UPLOT(NPLOT+24)  = AVGRAD
      UPLOT(NPLOT+25)  = TORQUE
      NPLOT = NPLOT+25                      ! Number of plots used so far
C==========Process Block 3===============================================

C---Perform roll bar calculations---------------------------------------
C
C   Neccessary Conditions:
C   1. Body 1 must be chassis
C   2. Body 2 must be lower front left control arm
C   3. Body 3 must be lower front right contol arm
C
C---Get the chassis transformation matrix

      ICHS = 1

      ACHS(1,1) = RB(38,ICHS)
      ACHS(2,1) = RB(39,ICHS)
```

```
      ACHS(3,1) = RB(40,ICHS)
      ACHS(1,2) = RB(41,ICHS)
      ACHS(2,2) = RB(42,ICHS)
      ACHS(3,2) = RB(43,ICHS)
      ACHS(1,3) = RB(44,ICHS)
      ACHS(2,3) = RB(45,ICHS)
      ACHS(3,3) = RB(46,ICHS)

C   Get a global postion vector components required to define a vector
C   form the right control arm CG to the Left control arm CG.

      DELTAP(1) = Q(1,3) - Q(1,2)
      DELTAP(2) = Q(2,3) - Q(2,2)
      DELTAP(3) = Q(3,3) - Q(3,2)

C---Calculate the length of the vector

      VECLEN = DSQRT( DELTAP(1)**2 + DELTAP(2)**2 + DELTAP(3)**2 )

C---Convert global postion vector to chassis coordinate system
C   and make it into a unit vector

      DXCH = ( DELTAP(1)*ACHS(1,1) +
     &         DELTAP(2)*ACHS(2,1) +
     &         DELTAP(3)*ACHS(3,1)  ) / VECLEN

      DZCH = ( DELTAP(1)*ACHS(1,3) +
     &         DELTAP(2)*ACHS(2,3) +
     &         DELTAP(3)*ACHS(3,3)  ) / VECLEN

C---Calculate the angle using the dot product between DXCH and a
C   vector along the chassis X axis

      DXCH = DMIN1 ( DXCH, 1.0D0 )
      ANG  = DACOS ( DXCH )
      ANG  = DSIGN ( ANG, DZCH )

C---Calculate the vertical arm force due to roll bar stiffness
C        Force  = K * angle
C
C        K = lbs/rad

      ARMFOR   = RSTIFF*ANG

C---Calculate the reaction torque acting about the chassis Y axis
C   based upon a moment arm of 43.06 inches from left arm CG
C   to right arm CG

      CHTOR = -43.06D0*ARMFOR

C---Convert the chassis torque to global system

      TQ(1) = CHTOR*ACHS(1,2)
      TQ(2) = CHTOR*ACHS(2,2)
      TQ(3) = CHTOR*ACHS(3,2)

C---Convert the chassis torque to the Euler Parameter Coordinate System

      CALL ETS ( Q(4,ICHS), TQ, TQE )
```

```
C---Append the reaction torque onto the chassis

      FRC(4,1) = FRC(4,1) + TQE(1) * 2.0D0
      FRC(5,1) = FRC(5,1) + TQE(2) * 2.0D0
      FRC(6,1) = FRC(6,1) + TQE(3) * 2.0D0
      FRC(7,1) = FRC(7,1) + TQE(4) * 2.0D0

C---Convert the roll bar vertical force in chassis to global system

      FP(1) = ARMFOR*ACHS(1,3)
      FP(2) = ARMFOR*ACHS(2,3)
      FP(3) = ARMFOR*ACHS(3,3)

C---Append the equal but opposite force to both left and right lower arms

      DO 1100 I=1,3
        FRC(I,2)=FRC(I,2)+FP(I)
        FRC(I,3)=FRC(I,3)-FP(I)
 1100 CONTINUE

C---Report out aux roll stiff data

      UPLOT(1+NPLOT) = ANG                 ! Roll Bar angle
      UPLOT(2+NPLOT) = ARMFOR              ! Roll Bar Force
      UPLOT(3+NPLOT) = CHTOR               ! Reaction Torque on Chassis
      UPLOT(4+NPLOT) = DXCH
      UPLOT(5+NPLOT) = DZCH
      NPLOT = NPLOT + 5                    ! Update number of plot variables used

C---Report out articulation angle of hitch

      IF (NB .GT. 15) THEN
        UPLOT(1+NPLOT) = -DATAN2(RB(41,16),RB(42,16)) +
     &                    DATAN2(RB(41,1),RB(42,1))
        NPLOT = NPLOT + 1
      END IF

      RETURN
      END

superi>
```

```
C---TIREF: Calculates the forces exerted on the tire through the road.

C===========Author and Modification Section===========================
C
C  Author:       James A. Aardema, Rick Mousseau, Roger Weahage
C
C  Date written: Unknown
C
C  Written on:
C
C  Modifications:
C
C====================================================================

C===========Algorithm Description=====================================
C
C  Purpose and use:      Calculates the slip angle, lateral,
C                        longitudinal, and normal tire forces for a
C                        point follower tire model.
C
C====================================================================


      SUBROUTINE TIREF ( I, Q, QD, QDD, FRC, ITIR, TIR, RB, A, IA,
     &                NB, NTR, MPTRS, NPTRS, NPRB, UDE, DUDE, NWHDE )


      IMPLICIT DOUBLE PRECISION (A-H,P-Z)

C===========Variable Descriptions=====================================
C
C---Arguments passed-------------------------------------------------
C
C  I......Current tire being calculated
C  Q......Array of generalized coordinates.
C  QD.....Array of velocities.
C  QDD....Array of acceleration values.
C  FRC....Array of generalized forces.
C  ITIR...Array of integer data from this module.
C  TIR....Array of real data from this module.
C  RB.....Array of rigid body real data.
C  A......Vector of all real data.
C  IA.....Vector of all integer data.
C  NB.....Number of rigid bodies.
C  NTR....Number of tire elements.
C  NPTRS..Number of real data per element.
C  MPTRS..Number of integer data per element.
C  NPRB...Number of real data per rigid body.
C  UDE....Array of user differential equations, Position terms
C  DUDE...Array of user differential equations, Velocity terms

      INTEGER NB, IA(0:1), ITIR(MPTRS,NTR), I,
     &        NTR, MPTRS, NPTRS, NPRB, NWHDE

      DOUBLE PRECISION A(0:1), Q(7,1), QD(7,1), QDD(7,I), FRC(7,1),
     &                 TIR(NPTRS,NTR), RB(NPRB,NB),
     &                 UDE(NWHDE), DUDE(NWHDE)
```

```
C
C---COMMON blocks-----------------------------------------------------
C
      INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]STEPHT.BLK'
      INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]PARAM.BLK'
      INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]POTEN.BLK'
      INCLUDE '[-.COMMON]CSTIFF.BLK'

C---STEPHT common Variables-------------------------------------------
C
C  H........Integration predictor step size.
C  HMAX.....Maximum integration predictor step size.
C  TSTART...Time at the start of the simulation.
C  TEND.....Time when simulation is to stop.
C  TSTEP....Integration step size.
C  T........Current time during the simulation.
C  HSTLEN...Length of the history arrays.
C  HSTPTR...Pointer to the last used location in the history arrays.
C  HSTCNT...Count of the number of time steps for which integration
C           history was saved.
C  HSTH.....Past history of the integration time step.
C  HSTK.....Past history of the integration order.
C  HSTERR...Past history of the integration error estimate.
C
C
C----PARAM.BLK Common Variables----------------------------------------
C
C  This file contains a number of constants which are used in various
C  subroutines throughout the code and are stored here to insure
C  accuracy and make any changes easier.
C
C    PI.......pi
C    TWOPI....two times pi
C    DEGRAD...degrees per radian
C    MCHEPS...machine epsilon
C    BODMOD...number of the rigid body module
C    CRVMOD...number of the curve module
C    INPEPS...epsilon value used to check error in normalized input
C             values
C
C---POTEN Common Variables---------------------------------------------
C
C    MSTAT.....Flag controling whether total energy is to be calculated.
C    V.........Scalar of potential energies.
C    VBGN......Working vector.
C    F.........Function value working vector.
C
C---RUNFLAT.BLK Common Variables---------------------------------------
C
C     RFRAD....Run Flat Radius
C     RFSTIF...Run Flat Stiffness
C     RFDAMP...Run Flat Damping
C
C---CSTIFF.BLK Common Variables-----------------------------------------
C
C     CSTIFF...Array containing cornnering stiff of front wheels
C
C---Local variables-----------------------------------------------------
C
C     IBDY.....ITIR(1,I)...Body number wheel is attached to
```

```
C     ICHS.....ITIR(2,I)...Body number defined as the chassis
C     IUTIL....ITIR(3,I)...Utility curve number
C     ITK......ITIR(4,1)...Vertical Spring rate Curve number
C     ILNG.....ITIR(5,1)...Torque Curve number
C     ISTR.....ITIR(6,I)...Steer Curve number
C     TYPE.....ITIR(7,I)...Model type
C     RC(1)....TIR(1,I)....Wheel center postion in local coordinates
C     RC(2)....TIR(2,I)
C     RC(3)....TIR(3,I)
C     RAD......TIR(4,I)....Tire Radius
C     RR.......TIR(5,I)....Rolling Resistance
C     TD.......TIR(6,I)....Tire Damping constant
C     TK.......TIR(7,I)....Tire Vertical Spring Stiffness
C     CALP.....TIR(8,I)....Lateral Stiffness of the tire
C     STRAG....TIR(9,I)....Steer angle
C     MU.......TIR(10,I)...Friction Coefficient
C     YAW......TIR(11,I)...Yaw angle of the wheel body
C     VX.......TIR(12,I)...Velocity of wheel center in road system
C     VY.......TIR(13,I)
C     VZ.......TIR(14,I)
C     TIRE1....TIR(15,I)...Global position of the tire center
C     TIRE2....TIR(16,I)
C     TIRE3....TIR(17,I)
C     TIREX....TIR(18,I)...Global postion of the tire bottom
C     TIREY....TIR(19,I)
C     TIREZ....TIR(20,I)
C     ZROAD....TIR(21,I)...Ground Elevation
C     DEFL.....TIR(22,I)...Tire Deflection - Ground Penetration
C     FSPR.....TIR(23,I)...Spring Force
C     FDAMP....TIR(24,I)...Damping Force
C     FNORM....TIR(25,I)...Normal Force
C     SLIP.....TIR(26,I)...Tire Slip
C     FLAT.....TIR(27,I)...Lateral force
C     S........TIR(28,I)...Longitudinal slip
C     FLONG....TIR(29,I)...Longitudinal force
C     GFRC.....TIR(30,I)...Wheel torque
C     PENRF....TIR(31.I)...Penetration into the run flat assembly
C     FRF......TIR(32,I)...Run flat force due to penetration onto run flat
C     ALGNTQ...TIR(33,I)...Aligning Torque due to lateral slip
C     FNTEMP...............Tempary Variable to hold normal force
C     ANGV.................Angular Velocity of the wheel
C     SCO..................Absoulute value of the longitudinal slip
C     FCOEF................Coefficient relating long force and normal force
C     FMAX.................Maximum force on tire allowed by friction
C     FTOT.................Magniutude of the force on the tire
C     RATIO................Ratio between Maximum and total force

      INTEGER   IBDY, ICHS, IUTIL, ITK, ILNG, ISTR, TYPE

      DOUBLE PRECISION RC(3), RAD, RR, TD, TK, CALP, STRAGL, MU,
     &                 YAW, VX, VY, VZ, TIRE1, TIRE2, TIRE3,
     &                 TIREX, TIREY, TIREZ, ZROAD,
     &                 DEFL, FSPR, FDAMP, FNORM, SLIP, FLAT,
     &                 S, FLONG, GFRC, FRF, PENRF,
     &                 FNTEMP, ANGV, SCO, FCOEF, FMAX, FTOT,
     &                 RATIO, ALGNTQ

C---Functions and subroutines---------------------------------------

      DOUBLE PRECISION FSPLIN, FLINEAR, CUBIC, CUBIC1, C
```

```
      EXTERNAL        FSPLIN, FLINEAR, CUBIC, CUBIC1, CARPET

      INTRINSIC       DABS, DSIGN, DCOS, DSIN, DATAN2,
     &                DSQRT, DMAX1

C===========Process Block============================================

C---Initialize the output quanities to zero in case wheel is off ground

      FLONG  = 0.0D0                  ! Tire Longitudinal force
      GFRC   = 0.0D0                  ! turning wheel torque
      FLAT   = 0.0D0                  ! Tire Lateral force
      ALGNTQ = 0.0D0                  ! Aligning Torque

      FSPR   = 0.0D0                  ! Tire Spring Force
      FDAMP  = 0.0D0                  ! Tire Damping Force
      FNORM  = 0.0D0                  ! Total Normal Force
      FRF    = 0.0D0                  ! Run Flat Force
      PENRF  = 0.0D0                  ! Penetration into run flat
      SLIP   = 0.0D0                  ! Lateral Slip
      S      = 0.0D0                  ! Longintudinal Slip

C---Calculate the tire-spring deflection.
C   Difference between road elevation and tire bottom elevation
C   Ground  penetration  if DEFL >  0.0
C   Wheel off the ground if DEFL <= 0.0

      TIREZ = TIR(20,I)
      ZROAD = TIR(21,I)
      DEFL  = ZROAD - TIREZ

C---Calculate the normal force from ground if the wheel has deflected
C   into the ground.  If the tire is not deflected there are no
C   forces on the tire, skip to the end

      IF ( DEFL .LE. 0.0D0 ) THEN
        DEFL = 0.0D0
        GOTO 1000
      ENDIF

C---The wheel has penetrated the ground so we must calculate tire forces

C---Get variables from ITIR and TIR arrays

C     IBDY  = ITIR(1,I)           ! Body number wheel is attached to
C     ICHS  = ITIR(2,I)           ! Body number defined as the chassis
      IUTIL = ITIR(3,I)           ! Utility curve number
      ITK   = ITIR(4,I)           ! Vertical Spring rate Curve number
      ILNG  = ITIR(5,1)           ! Torque Curve number
      ISTR  = ITIR(6,I)           ! Steer Curve number
C     TYPE  = ITIR(7,I)           ! Model type

C     RC(1) = TIR(1,I)            ! Wheel center postion in local coordinates
C     RC(2) = TIR(2,I)
      RC(3) = TIR(3,I)
      RAD   = TIR(4,I)            ! Tire Radius
      RR    = TIR(5,I)            ! Rolling Resistance
      TD    = TIR(6,I)            ! Tire Damping constant
      TK    = TIR(7,I)            ! Tire Vertical Spring Stiffness
```

```
      CALP   = TIR(8,I)              ! Lateral Stiffness of the tire
C     STRAGL= TIR(9,I)              ! Steer angle
      MU     = TIR(10,I)             ! Friction Coefficient

      YAW    = TIR(11,I)             ! Yaw angle of the wheel body
      VX     = TIR(12,I)             ! Velocity of wheel center in road system
      VY     = TIR(13,I)
      VZ     = TIR(14,I)
C     TIRE1 = TIR(15,I)              ! Global position of the tire center
C     TIRE2 = TIR(16,I)
C     TIRE3 = TIR(17,I)
C     TIREX = TIR(18,I)              ! Global postion of the tire bottom
C     TIREY = TIR(19,I)
C     TIREZ = TIR(20,I)
C     ZROAD = TIR(21,I)              ! Ground Elevation

C---Define the normal force, test for a constant spring or curve data

      IF ( ITK .EQ. 0 ) THEN                        ! No Spring Curve defined
        FSPR  = TK * DEFL                           ! Tire Stiffness
      ELSE
        FSPR = FSPLIN ( DEFL, 0.D0, ITK, 1, A, IA, 0, 0 )
      ENDIF

C---Define potential energy for static analysis

      IF ( MSTAT .LE. 1 ) THEN
        IF ( ITK .EQ. 0 ) THEN
          V = V + TK * DEFL**2 / 2.0D0
        ELSE
          V = V + FSPLIN ( DEFL, 0.D0, ITK, 1, A, IA, -1, 0 )
        ENDIF
      ENDIF

C---Define the normal force resulting from tire damping

      FDAMP = -VZ * TD * CUBIC1(DEFL)      ! Tire Damping force

C---The radius of the run flat assembly is given by (RFRAD)
C   Add 1 inch to this radius to account for tire carcuss thickness
C   Check to see if the  tire has deflected into the run flat assembly
C   If TRUE, then add additional forces
C   Run flat stiffness is stored in RFSTIF
C   Run flat damping is stored in RFDAMP
C   Use cubicl with a tolerance of plus on minus 1/16 inch

      PENRF = RFRAD + 1.0D0 + 0.0625D0  - (RAD-DEFL)     ! Run flat penetration
      IF ( PENRF .GT. 0.0D0 ) THEN
        FRF =   RFSTIF * PENRF * CUBIC1(8.0D0*PENRF)
     &          + RFDAMP * (-VZ) * CUBIC1(8.0D0*PENRF)     ! Run flat force
        FRF = DMAX1(0.0D0,FRF)
      ELSE
        PENRF = 0.0D0                                     ! Reset for reporting
        FRF   = 0.0D0
      ENDIF

C---Sum up all the forces that may act on the tire
C   Limit the normal force so that it can not go negative

      FNORM = FSPR + FDAMP + FRF                    ! Normal force on tire
```

```
      FNORM = DMAX1(0.0D0,FNORM)

C---If the tire is off the ground there are no longitudinal forces,
C   lateral forces, or torques turning the wheel.
C   else if the tire has penetrated the ground then calculate the
C   tire slip angle.

      IF ( DSQRT ( VX*VX + VY*VY ) .GT. 1.D-2 ) THEN
        SLIP = -DATAN2 (VX, VY)
      ELSE
        SLIP = 0.D0
      END IF

C---For the front tires use the Lateral Force Data and Aligning Torque
C   Date from the first data arrays

      IF ( I .EQ. 1 .OR. I .EQ. 2 ) THEN ! Front Tires

C---Save the normal force in a temporary variable
C   Calculate lateral force from the carpet plot
C   Carpet plot is a family of normal force Curves versus slip angle

        FNTEMP = FNORM
        FLAT = CARPET(CSTIFF(I),SLIP,FNTEMP,I,1,NTR)

C---Calculate aligning torque from carpet plot

        ALGNTQ = CARPET(C,SLIP,FNTEMP,I,4,NTR)
      END IF

C---For the Rear tires use the Lateral Force Data and Aligning Torque
C   Date from the second data arrays

      IF ( I .EQ. 3 .OR. I .EQ. 4 ) THEN ! Rear Tires

C---Save the normal force in a temporary variable
C   Calculate lateral force from the carpet plot
C   Carpet plot is a family of normal force Curves versus slip angle

        FNTEMP = FNORM
        FLAT = CARPET(CSTIFF(I),SLIP,FNTEMP,I,2,NTR)

C---Calculate alinging torque from carpet plot

        ALGNTQ = CARPET(C,SLIP,FNTEMP,I,5,NTR)
      END IF

C---For the trailer tires use the Lateral Force Data and Aligning Torque
C   Date from the second data arrays

      IF ( I .EQ. 5 .OR. I .EQ. 6 ) THEN ! Trailer tires

C---Save the normal force in a temporary variable
C   Calculate lateral force from the carpet plot
C   Carpet plot is a family of normal force Curves versus slip angle

        FNTEMP = FNORM
        FLAT = CARPET(C,SLIP,FNTEMP,I,3,NTR)

C---Calculate alinging torque from carpet plot
```

```
        ALGNTQ = CARPET(C,SLIP,FNTEMP,I,6,NTR)
      END IF

C---Define the longitudinal force for the turning wheel model
C   Get local velocity in the steer direction
C   Get the angular velocity of the wheel; Postive velocity is in the
C   the negative Y direction

C   Defn: Long Slip = ( Velocity - R*W ) / Velocity

C   if Vel > R*w  then slip > 0.0   Wheel is turning to slow causing slip
C   if Vel = R*w  then slip = 0.0
C   if Vel < R*w  then slip < 0.0   Wheel is turning to fast causing slip

      ANGV = UDE( I+NTR )                        ! Angular velocity of wheel
      IF ( DABS(VY) .GT. 0.0001D0 ) THEN
        S = ( VY + ANGV*(RAD-DEFL)) / VY         ! Definition of Long. Slip
      ELSE
        S = 0.D0
      END IF
      SCO = DABS( S )                             ! temporary variable
      IF ( SCO .GT. 1.D0 ) SCO=1.D0               ! Limit slip

C---The Utility spline curve is used for calculating slip.
C   Longitudinal force = Fcoef * Fnorm

      FCOEF =  FSPLIN ( SCO, 0.D0, IUTIL, 1, A, IA, 0, 0 )
      FLONG = -DSIGN   ( FCOEF*FNORM, S )

C---Limit the long. and lateral forces using the friction ellipse (circle).

      FMAX  = MU*DABS(FNORM)
      FTOT  = DSQRT(FLONG**2 + FLAT**2)
      IF ( FTOT .GT. FMAX ) THEN
        RATIO = FMAX/FTOT
        FLAT  = RATIO*FLAT
        FLONG = RATIO*FLONG
      END IF

C---Calculate the torque due to the longitudinal force causing the wheel
C   to turn

      GFRC = FLONG * ( RAD-DEFL )

 1000 CONTINUE

C---Save values in ITIR and TIR arrays

      TIR(22,I) = DEFL               ! Tire Deflection - Ground Penetration
      TIR(23,I) = FSPR               ! Spring Force
      TIR(24,I) = FDAMP              ! Damping Force
      TIR(25,I) = FNORM              ! Normal Force
      TIR(26,I) = SLIP               ! Tire Slip
      TIR(27,I) = FLAT               ! Lateral force
      TIR(28,I) = S                  ! Longitudinal slip
      TIR(29,I) = FLONG              ! Longitudinal force
      TIR(30,I) = GFRC               ! Wheel torque
      TIR(31,I) = PENRF              ! Penetration into run flat
      TIR(32,I) = FRF                ! Force due to run flat
```

```
TIR(33,I) = ALGNTQ            ! Aligning Torque

RETURN
END
```

APPENDIX D

Driver Model FORTRAN Source Code

```
USER49: Calculates User supplied values for the driving function

============Author and Modification Section============================

 Author:       James A. Aardema

 Date written: 07/01/87

 Written on:

 Modifications:

=======================================================================

============Algorithm Description======================================

 Purpose and use:

 Error conditions:

 Machine dependencies: none

 Called By: FUN49.FOR

=======================================================================


      SUBROUTINE USER49 ( IRE, FN, AJ, ND, DRV, IDRV, Q, QD, A, IA,
     &                    MPTRS, NPTRS, RB, NPRB, QDR, QDDR, NB, RVLT,
     &                    TRAN, CYL, NPRT, NPTRN, NPCYL, QDD,
     &                    CST, CSTD, CSTDD, IDRIVER )

============Variable Descriptions======================================

---Arguments passed----------------------------------------------------

   ND    ................. number of driving constraint
   IA    ................. total integer array
   A     ................. total real array
   IDRV  ...IA(MP(12))... integer array for the driving constraint
   NPTRS ................. real data item per constraint
   TRAN ................ Real data for the translational joint.
   CYL ................. Real data for the cylindrical joint.
   RVLT ................ Real data for the revolute joint.
   NPTRN ............... Number of real data per translational joint.
   NPCYL ............... Number of real data per cylindrical joint.
   NPRT ................ Number of real data per revolute joint.
   DRV   ....A(NP(12))... real data for driving constraint
   Q     ....A( N1  ).... position
   QD    ....A( N2  ).... velocity
   QDD   ....A( N3  ).... acceleration
   QDR   ....Q(IQ(MM))... position
   QDDR  ....QD(IQ(MM)).. velocity
   AJ    ....A( N5  ).... Jacobian matrix
   FN    ....A( N8  ).... temporary array for the constraint equation
                          r.h.s. of velocity or acceleration equation
   IRE   ...IA( M7  ).... flag for redundant constraint
   NB    ................. number of rigid bodies in the model
   CST   ... driving function
```

```
   CSTD  ... first derivative of driving function
   CSTDD ... second derivative of driving function
   IDRIVER...Current driver being analyzed

     INTEGER  MPTRS, NPTRS, ND, IDRV(MPTRS,ND), IA(0:1),
    &         IRE(1),NPRB, NB, NPTRN, NPCYL, NPRT, IDRIVER

     DOUBLE PRECISION  FN(1), AJ(1), DRV(NPTRS,ND), Q(7,1), QD(7,1),
    &                  RB(NPRB,NB), QDR(1), QDDR(1), A(0:1),
    &                  TRAN(NPTRN,1), CYL(NPCYL,1), RVLT(NPRT,1),
    &                  QDD(7,1), CST, CSTD, CSTDD

 ---COMMON blocks-----------------------------------------------------

     INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]STEPHT.BLK'

     INCLUDE '[-.COMMON]UPLOT.BLK'

 ---COMMON Variables-------------------------------------------------

 ---STEPHT common block variables------------------------------------

  H........Integration predictor step size.
  HMAX.....Maximum integration predictor step size.
  TSTART...Time at the start of the simulation.
  TEND.....Time when simulation is to stop.
  TSTEP....Integration step size.
  T........Current time during the simulation.
  HSTLEN...Length of the history arrays.
  HSTPTR...Pointer to the last used location in the history arrays.
  HSTCNT...Count of the number of time steps for which integration
           history was saved.
  HSTH.....Past history of the integration time step.
  HSTK.....Past history of the integration order.
  HSTERR...Past history of the integration error estimate.

 ---UPLOT.BLK Common Variables---------------------------------------

   UPLOT....Array for storing user variables
   NPLOT....Number of plot variables used

 ---Local variables--------------------------------------------------

    K11.... EQ.0 : do not evaluate Jacobian matrix
            EQ.1 : evaluate Jacobian matrix
    K22.... EQ.1 : evaluate Jacobian matrix
            EQ.2 : evaluate constraint equation
            EQ.3 : evaluate r.h.s. of the velocity equation
            EQ.4 : evaluate r.h.s. of the acceleration equation
   JB1   ... first body number of driving constraint is imposed
   JB2   ... second body number of driving constraint is imposed
   JTYPE .. type of driving constraint joint.
            =1 Revolute joint
            =2 Cylindrical joint
            =3 Translational joint
   FTYPE .. Driving function.
             EQ.1 : polynomial driving function
                    coeff1 + coeff2*T + coeff3*T**2 + coeff4*T**3
             EQ.2 : harmonic driving function
                    coeff1 + coeff2 * SIN ( coeff3*T - coeff4 )
```

```
          EQ.3 : general driving function

          coefficients of the driving functions
          polynomial          harmonic            general

 coeff1:  constant term       constant term       not used
 coeff2:  1st order coef.     amplitude           not used
 coeff3:  2nd order coef.     frequency           not used
 coeff4:  3rd order coef.     phase shift         not used

DTYPE ...Type of constraint defined:
          EQ.1 : constrain Xpi
          EQ.2 : constrain Ypi
          EQ.3 : constrain Zpi
          EQ.4 : constrain Xpj - Xpi
          EQ.5 : constrain Ypj - Ypi
          EQ.6 : constrain Zpj - Zpi
          EQ.7 : constrain distance between two position
          EQ.8 : relative angle constraint on revolute or cylin-
                 drical joint
          EQ.9 : constrain relative position on translational or
                 cylindrical joint
FT     ... value of general curve
NZHS   ... pointer for Jacobian array
ITEMP  ... temporary value
PNTR   ... pointer into the input data array
DNAME  ... name of a distance driver
JN ... joint number.
ICHS...Body number of the chassis

  INTEGER  JB1, JB2, DTYPE, JTYPE, K11, K22, NZHS, ITEMP,
 &         PNTR, FTYPE, JN, ICHS

  DOUBLE PRECISION  ACHS(3,3), PHI, STEER, DSTEER, DDSTEER

  REAL Y(5), DFWOUT, DFWOLD, DF, DFVEL, DFACC, DFF
  REAL TDRIV

  CHARACTER*20  DNAME


---Functions and subroutines-------------------------------------------

  EXTERNAL  FSPLIN, SIMDR, ELMDR, DISTDR, TRANDR, SINE, COSINE,
 &          TRULEN, DRIVER, FILTR1, FILTR2
  EXTERNAL EULANG

  INTEGER   TRULEN

  DOUBLE PRECISION  FSPLIN
  DOUBLE PRECISION YANIM(3)

  INTRINSIC  DCOS, MOD, DSIN, DABS, DATAN, DSIGN, DATAN2,
 &           SNGL, DBLE
  SAVE DFWOLD

======================================================================


===========Process Block===============================================
```

```
      DFWOUT = 0.0
      STEER = 0.0
C
C---Get the chassis body number

      ICHS = IDRV(1,IDRIVER)   ! IDRIVER is the current driver being analyzed

 ---Get the chassis transformation matrix

      ACHS(1,1) = RB(38,ICHS)
      ACHS(2,1) = RB(39,ICHS)
      ACHS(3,1) = RB(40,ICHS)
      ACHS(1,2) = RB(41,ICHS)
      ACHS(2,2) = RB(42,ICHS)
      ACHS(3,2) = RB(43,ICHS)
      ACHS(1,3) = RB(44,ICHS)
      ACHS(2,3) = RB(45,ICHS)
      ACHS(3,3) = RB(46,ICHS)

   Call to EulAng for Animation Output

       YANIM(1) = Q(2,ICHS) / 12.
       YANIM(2) = Q(1,ICHS) / 12.
       YANIM(3) = -(Q(3,ICHS) - RB(20,ICHS)) / 12.
       CALL EULANG(T, YANIM, ACHS)


      Y(2) = SNGL( ACHS(1,1)*QD(1,ICHS) +
     &             ACHS(2,1)*QD(2,ICHS) +
     &             ACHS(3,1)*QD(3,ICHS))/12.0   ! lateral velocity in body cs

 ---Get the current vehicle global position

      Y(1) = SNGL(Q(1,ICHS))/12.0     ! LATERAL DISPLACEMENT
      Y(5) = SNGL(Q(2,ICHS))/12.0     ! FORWARD DISPLACEMENT

      Y(3)  = -SNGL(RB(34,ICHS))       ! YAW RATE - GLOBAL
      PHI = DATAN2(ACHS(1,2), ACHS(2,2) )
      Y(4) =   SNGL(PHI)

       UPLOT(NPLOT+1) = DBLE(Y(1))
       UPLOT(NPLOT+2) = DBLE(Y(2))
       UPLOT(NPLOT+3) = DBLE(Y(3))
       UPLOT(NPLOT+4) = DBLE(Y(4))
       UPLOT(NPLOT+5) = DBLE(Y(5))

 ---Calculate the steering control from the steering model
    If STEER > 0.0 Turn Right
    If STEER < 0.0 Turn Left

      TDRIV = SNGL(T)
       CALL DRIVER ( TDRIV, Y, DFWOUT, DFWOLD )

       CALL FILTR1 ( TDRIV, DFWOUT, DF, DFVEL, DFACC )

       UPLOT(NPLOT+6) = DBLE(DF)
       UPLOT(NPLOT+7) = DBLE(DFVEL)
       UPLOT(NPLOT+8) = DBLE(DFACC)
```

```
      CALL FILTR2 ( TDRIV, DF, DFF, DFVEL, DFACC )
      DFWOLD = DFF

      UPLOT(NPLOT+9)  = DBLE(DFF)
      UPLOT(NPLOT+10) = DBLE(DFVEL)
      UPLOT(NPLOT+11) = DBLE(DFACC)

      STEER   = DBLE(DFF)
      DSTEER  = DBLE(DFVEL)
      DDSTEER = DBLE(DFACC)

      UPLOT(NPLOT+12) = STEER
      UPLOT(NPLOT+13) = DSTEER
      UPLOT(NPLOT+14) = DDSTEER

---Calculate the pitman arm angle from the tire steering angle
   The ratio between steering angle and pitman arm angle is 1.166D0

      CST   = 1.166D0 * STEER
      CSTD  = 1.166D0 * DSTEER
      CSTDD = 1.166D0 * DDSTEER


---Pitman arm travel is limited to 38.25 degrees or 0.668 radians

      IF ( DABS(CST) .GE. 0.668D0 ) THEN
         CST   = DSIGN(0.668D0,CST)
         CSTD  = 0.0D0
         CSTDD = 0.0D0
      ENDIF
      NPLOT = NPLOT + 14

      RETURN
      END
superi>
```

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